

news



Healthy water resources – balancing the needs of humans and the environment

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Rik Eggen, molecular biologist, is Deputy Director of Eawag and lectures at the ETH Zurich.

A 75-year high-wire act

As far as water is concerned, Switzerland is in a privileged position. Even when rainfall is as exceptionally low as it has been this spring, water is not a scarce commodity in this country. In addition, Switzerland generally takes its responsibilities as Europe's "water tower" very seriously. This is shown by its successful management of water resources and infrastructure – today as in the past. But even an exemplary approach to water management inevitably involves (sometimes significant) degradation of the aquatic environment and the landscape.

And pressures on water resources are increasing worldwide. Whichever sector one considers – water supply, industry, agriculture, shipping, power generation or tourism – the resource-use demands of the various actors in our "multi-option society" show no signs of abating. At the same time, there are efforts to preserve or restore the remaining aquatic habitats; ultimately – however justified they may be – these are also demands coming from just part of our society.

These competing aspirations – moderate, sustainable water use versus adequate water protection, power generation versus the safeguarding of aquatic ecosystem services – need to be weighed up and priorities have to be set: a veritable balancing act! Research also faces major challenges, as it has a duty to provide policymakers with sound scientific knowledge and a reliable basis for decision-making.

Eawag has been doing this successfully for 75 years now. How what was originally the ETH Advisory Centre for Wastewater Treatment and Drinking Water Supply became one of the world's leading aquatic research institutes is one of the topics covered in this edition of Eawag News. One of the constants in Eawag's history has certainly been a desire to help solve practical problems through high-quality and transdisciplinary scientific work. This has also sometimes involved a balancing act between various disciplines, or between basic research and applied science. Thanks to its consulting and training activities, Eawag has come to be valued by professionals as an important expert partner.

This magazine aims to give readers an idea of the questions currently preoccupying Eawag researchers – in other words, the water-related issues of today and tomorrow. Monitoring and analysis of drinking water, urban water management infrastructure, cleantech in wastewater management, sanitation in developing countries or evolutionary ecology in aquatic environments – whatever the topic may be, these articles reflect, firstly, the various interests represented within society with regard to water resources and, secondly, the diversity of perspectives on the water system which characterizes Eawag's integrated approach. The results of this approach, not infrequently, are pioneering concepts and innovative technologies which are ahead of their time.

Even in the water tower of Switzerland, the health and safety of water resources cannot be taken for granted. The challenge of the future is to achieve a judicious balance between a variety of sometimes conflicting needs. Cutting-edge integrated research can help to secure the provision of water for healthy societies and the protection of water for healthy ecosystems.

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75 Years Eawag

Aquatic research and water protection: ongoing challenges

The history of Eawag reflects an increasingly integrated approach to water protection: It has come to involve not just the improvement of treatment methods for wastewater and drinking water, but early detection of problems and prevention; not just the management of emergencies, but efforts to understand fundamental processes; not just a national focus, but an international perspective. Even after 75 years of research, teaching and consulting, the protection of water resources remains an ongoing challenge.

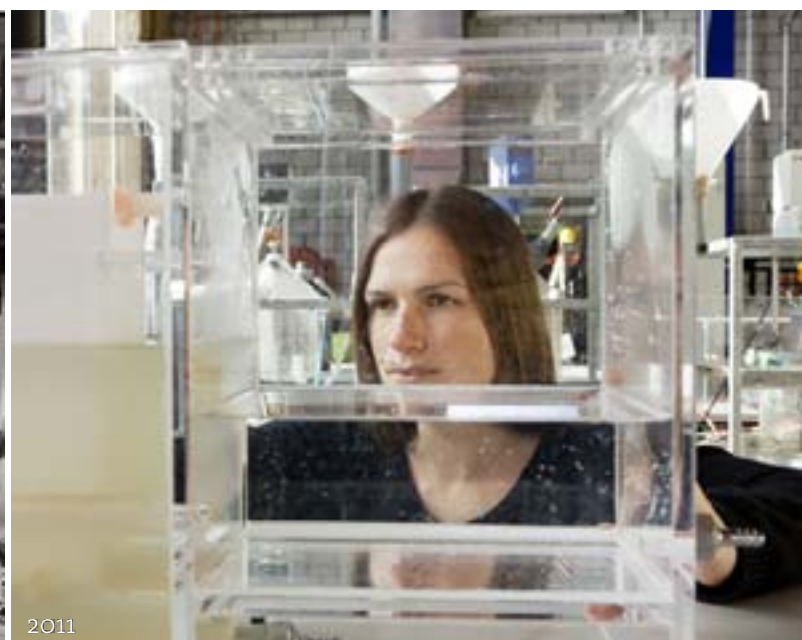
In the early 20th century, discharges of untreated or only mechanically treated wastewater from growing urban areas, as well as industrial effluents, meant that the condition of Swiss rivers and lakes was increasingly dire. Fishermen in particular began to protest about this state of affairs, calling on the federal authorities to take action against water pollution.

Lack of wastewater experts in Switzerland. Before the Second World War, hardly any professionals in Switzerland specialized in the planning and construction of wastewater treatment plants. The few experts available came from Germany. On 1 January 1936, the Federal Council therefore established the ETH Advisory Centre for Wastewater Treatment and Drinking Water Supply.

The Hygiene Institute (led by Willy von Gonzenbach; see Box on page 5) and the Hydrological Engineering Test Facility (established in 1930 and headed by Eugen Meyer-Peter) formed the basis of the new institution. It initially employed one chemist, one engineer and one biologist.

As well as providing advisory services for cantonal and communal authorities, it focused on research and education in the field of wastewater systems and on monitoring water quality so as to gauge the effectiveness of the new systems. As early as 1938, the Advisory Centre established a test facility on the site of the Zurich municipal wastewater treatment plant at Werdhölzli, where treatment processes could be developed and studies carried out on the self-cleansing capacity of surface waters. The facility was

Eawag laboratory and experimental set-ups: measurement of radioactivity in river water samples (left) and testing a plastic membrane used to remove viruses and bacteria from drinking water without the need for chemicals or a pump (right).



Stefan Kubli

relocated to the nearby Tüffenwies site in 1950, and to the Dübendorf site in 2001. Eawag's early studies were concerned not only with biological wastewater treatment, but also with methods of drinking water disinfection which could offer an alternative to chlorination – e. g. involving ozone, silver or UV radiation.

The beginnings of an integrated approach. In 1946, the Advisory Centre – now employing 24 people – became a fully-fledged institute, known as Eawag (i.e. the Federal Institute of Water Supply, Wastewater Treatment and Water Pollution Control). Alongside the Biology and Chemistry departments, Groundwater Geology and Civil Engineering departments were established. The first Director, serving until 1952, was Ulrich A. Corti, a chemist and active ornithologist. Although Eawag focused on practical wastewater treatment requirements at the cantonal and communal level, Corti was already developing long-term, ecological concepts and wrote papers on the function of surface waters as habitats. However, the value of this work was only recognized much later.

Venturing into politics. In 1952, Otto Jaag, who lectured in Hydrobiology and Limnology as well as Cryptogamic Botany at the ETH Zurich, was appointed as Director of Eawag. Jaag had already displayed a deep personal commitment to the introduction of a constitutional article on water pollution control. This article was approved in a popular vote in 1953, with no less than 81.4 per cent in favour. The high level of public support for water protection was largely due to Otto Jaag's promotion of the cause.

His advocacy was not misplaced, as growing consumption of energy and resources after the Second World War had left its mark on natural waters. Environmental protection agencies did not yet exist. In 1960, barely 10 per cent of the population had a connection to a centralized wastewater treatment plant. Riverbanks were used as dumps, and swimming in lakes was often prohibited. Jaag saw that the Water Protection Act lacked teeth and pressed for a revision – in particular, for a more active policy on subsidies. A revision (with a new article on subsidies) was passed in 1962, and a new Act in 1971 paved the way for expansion of the sewer network and treatment infrastructure. Today, around 97 per cent of all wastewater in Switzerland is treated at modern plants.

WWTPs alone insufficient. A similar "enforcement vacuum" arose after new water protection provisions – based not least on work carried out by Eawag – had been adopted in an Ordinance (1975) and an Act (1991), calling for careful use of water resources and ecologically adequate residual flows. While it was thus recognized at the federal level that wastewater treatment plants and reasonably clean water are not in themselves sufficient for integrated water protection, quantitative protection measures (including river restoration) and efforts to increase residual flows proceeded at a slow pace.

With the latest revision of the Water Protection Act, which came into force at the beginning of 2011, this should now change. More funding is to be made available, and the cantons are legally

A mirror of water protection in Switzerland

The creation of Eawag has a complex prehistory, reflecting the development of water protection in Switzerland. The end of the 19th century saw a rapid expansion of knowledge about the origins and spread of diseases. In 1894, the Institute of Hygiene and Bacteriology was established at the ETH Zurich by Otto Roth, a student of Robert Koch (who discovered the tubercle bacillus). At that time, the main concern was "protection of human labour against environmental hazards, accidents and acute or chronic poisoning at the workplace". But Willy von Gonzenbach, who took over from Roth in 1920, recognized the risks posed to the environment and human health by the pollution of lakes and rivers. In 1887, moreover, a Limnology Committee had been set up by the Swiss Scientific Society to study lakes, including their functioning and flora and fauna.

The occurrence of epidemics in Switzerland was prevented by the tapping of spring and ground water and the introduction of treatment steps involving sand filtration and, from 1910, also chlorine disinfection. But mains water supplies and new sanitary installations led to a sharp increase in water consumption, and the problem of disposal became more acute. Separate collection of faecal waste in buckets was therefore gradually replaced by waterborne sewage systems. While this neatly solved hygiene problems in urban areas, it also exacerbated visible pollution of surface waters, since wastewater was discharged into rivers untreated or, later, at best after mechanical treatment.

required to allow rivers more space so as to permit near-natural development, as far as possible, and to assure flood protection. Here, too, Eawag has supplied scientific foundations, arguments and tools, with research projects on integrated watershed management (e.g. Rhône/Thur, 2005), river assessment methods (Modular Stepwise Procedure, from 1981), or the mitigation of diffuse pollution.

Contract research and consulting. Up until the 1960s, much of Eawag's work was carried out for third parties, especially cantons and communes. In 1970, 37 per cent of the total expenditures of around CHF 3.4 million was covered by income from contract work. In his annual reports, Jaag regularly complained that staff were overstretched by commitments of this kind: "As regards the extent of the institute's activities, it may be noted that this year all

employees have again been continuously stretched to the limit, and indeed that some of them have struggled to complete their assignments on schedule with the necessary care.”

By 2010, “miscellaneous revenues” accounted for only a small percentage of total expenditures of around CHF 60 million. Contract work is now only undertaken if the associated research questions are of interest to Eawag. At the same time, research-project funding of around CHF 15 million was obtained from second-party and third-party sources (e.g. EU research programmes or foundations).

Commitment to developing countries. Under Jaag, in addition to the time-consuming contract work, basic research was of course also carried out – for example, on lake eutrophication, chemical and biological processes in groundwater, the self-cleansing capacity of surface waters, or the dimensioning of biological treatment plants. Scientific activities were further strengthened in 1960, when Eawag took over the Hydrobiological Laboratory at Kastanienbaum from the Lucerne Scientific Society (see Box on page 7). In 1968, the WHO International Reference Centre for Waste Disposal was also established at Eawag; in 1992, this became the Department of Water and Sanitation in Developing Countries (Sandec).

In 1970, after various abortive planning efforts and a great deal of toing and froing – Eawag staff worked at up to seven differ-

ent sites on the Zurich campus, as well as at the Kastanienbaum centre and the Tüffenwies test facility – the new office and laboratory building at Dübendorf was inaugurated. The institute now comprised 8 departments, with 110 employees. Biology, Chemistry, Geology and Civil Engineering had been supplemented by the following departments: Limnology (1952), Solid Wastes (1955), Radiology (1956) and Fishery Sciences (1969). Also in 1970, Eawag became an affiliated institute of the ETH Zurich; in 1993, it attained independence (within the ETH Domain) as the Swiss Federal Institute of Aquatic Science and Technology.

Closer ties with the ETH Zurich. Despite Eawag’s new status as an affiliated institute, Werner Stumm – a chemist, who became Director in 1970 – sought to establish closer ties with the ETH and other higher education institutions. In 1979, he launched a postgraduate course in Urban Water Management and Water Pollution Control, and in 1987 he helped to develop an Environmental Sciences course. Stumm reinvigorated the institute by actively recruiting a new generation of scientists.

This group of young scientists included the physicist Dieter Imboden, who is now President of the National Research Council. Imboden – like Ueli BUNDI (see interview on page 10) – identifies as one of the key success factors for Eawag in the post-1970 period the fact that it concentrated on multidisciplinary understanding of systems and processes, rather than allowing research

Experimental systems: at the Zurich Tüffenwies site (left), with artificial channels for biological self-cleansing of rivers, and at the Dübendorf testing facility (right), for sludge treatment designed to improve nitrogen removal and reduce energy at WWTPs.



1950



2011

Stefan Kubli



1940



2010

Monika Estermann

The lakeside laboratory at Kastanienbaum before it was taken over by Eawag (left) and a microcosm system used for long-term experiments in evolutionary biology (right).

Kastanienbaum: from lakeside laboratory to Centre for Ecology, Evolution and Biogeochemistry

In 1916, with support from private benefactors, the Lucerne Scientific Society established the Hydrobiological Laboratory at Kastanienbaum on Lake Lucerne. The key figures in this enterprise were the physician Fritz Schwyzer and the high school teacher Hans Bachmann, who chaired the Swiss Scientific Society's Hydrobiology Committee until 1940. The small laboratory was used by specialists from Switzerland and abroad for studies and courses on the chemistry, plankton, aquatic plants and fish of Lake Lucerne and other waterbodies.

In 1920, on the basis of work carried out at Kastanienbaum, the *Schweizerische Zeitschrift für Hydrologie* was launched, which in 1989 was renamed *Aquatic Sciences* – a renowned journal still published today with significant input from Eawag. Since 1960, the Limnology Research Centre (FZL) has been run by Eawag. The facilities available were expanded by the purchase of the "Seeheim" property in 1968 and the construction of a new building in 1976. Today, over 100 people work at Kastanienbaum, and the FZL has become the Centre for Ecology, Evolution and Biogeochemistry (CEEB).

Research at "KB" (as the site is known internally) has always focused on chemical, physical and biological processes in Lake Lucerne and other Swiss lakes. There have been major studies on the importance of the nutrients phosphorus and nitrogen and transformation processes for lake eutrophication. Investigations of plankton, sediments and soil organisms documented the progressive degradation of the lake in the 1960s and 1970s – but also its recovery following the introduction of ring sewerage systems and phosphorus elimination at treatment plants. Multidisciplinary projects studied the function of complex environmental systems, e.g. the benefits of artificial mixing for lake remediation, or the impacts of heavy metals.

In fisheries biology, the emphasis has shifted away from lake management for yield maximization towards efforts to preserve species and habitat diversity in all types of natural waters. The focus is no longer on acute fish kills (as in the 1970s), but on the adaptability of species and ecosystems in a changing environment, and the rise and fall of species in evolutionary processes.

questions to be dictated by specific problems. This approach was supported by mathematical models, which – thanks to increasingly powerful IT systems – permit ever-more precise analyses and predictions, e.g. of internal mixing processes in lakes.

Imboden also cites Eawag's outstanding analytical capacity, which frequently made it possible to detect and explain problems caused by new substances. Another hallmark of Stumm's directorship was growing internationalization, a development which

opened up career opportunities for Eawag staff all over the world. This international network, which has been continuously expanded, also facilitated research collaborations in areas where Eawag has less in-house expertise – e.g. efficient use of water in agriculture, impacts of climate change, or treatment of industrial effluents.

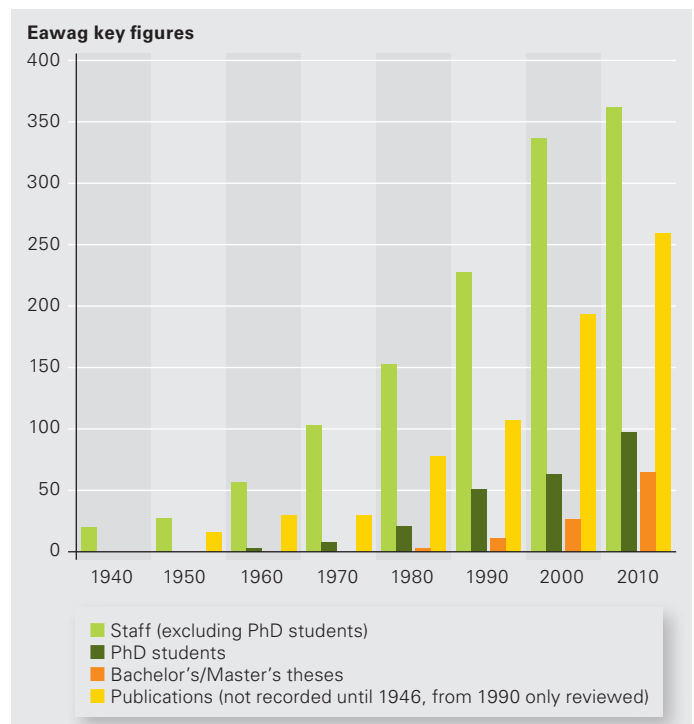
As well as solid wastes, Eawag began to take an interest in other sources of pollution which cannot be readily monitored,

Professors based at Eawag (all ETH Zurich, unless otherwise indicated, for adjunct professors see page 13)

	Served at Eawag	Chair
Willy von Gonzenbach	1936–1945	Hygiene and Bacteriology
Eugen Meyer-Peter	1936–1945	Hydraulic Engineering
Otto Jaag	1952–1970	Hydrobiology, Wastewater Treatment and Water Pollution Control
Arnold Hörler	1954–1968	Sewerage, Wastewater Treatment and Sanitary Engineering
Karl Wuhrmann	1946–1980	Microbiology
Rudolf Braun	1955–1983	Waste Management
Kurt Grob	1974–1985	High-Resolution Gas Chromatography (Kantonsschule Zurich)
Werner Stumm	1952–1992	Water Pollution Control
Heinz Ambühl	1952–1994	Hydrobiology (Associate Professor)
Jürg Hoigné	1974–1995	Aquatic Chemistry
Richard Heierli	1968–1970	Sanitary Engineering (Associate Professor)
Geoffrey Hamer	1980–1992	Technical Biology
Peter Baccini	1974–2004	Resource and Waste Management
James Ward	1995–2002	Aquatic Ecology
Dieter Imboden	1988–1999	Environmental Physics
René Schwarzenbach	1977–2004	Environmental Chemistry
Alexander Zehnder	1992–2004	Environmental Biotechnology
Willi Gujer	1992–2011	Urban Water Management
Bernhard Wehrli	Since 1988	Aquatic Chemistry
Urs von Gunten	Since 1989	Drinking Water Treatment (EPFL) and adjunct professor (ETHZ)
Jukka Jokela	Since 2005	Aquatic Ecology
Ole Seehausen	Since 2005	Aquatic Ecology and Evolution (Berne University)
Martin Ackermann	Since 2006	Molecular Microbial Ecology (Associate Professor)
Janet Hering	Since 2007	Environmental Biogeochemistry (ETH Zurich), Environmental Chemistry (EPFL)
Eberhard Morgenroth	Since 2009	Urban Water Management

such as road and roof runoff, combined sewer overflow emissions or agricultural pesticides.

More engagement with society and industry. In 1992, the biochemist Alexander Zehnder became Director of Eawag. Recognizing that pressures on the environment are largely determined by social processes, he set up a Human Ecology group to supplement the institute's scientific and engineering activities. The ability to understand or even control social processes is essential for the transition to more environmentally sound forms of life and economic activity. Accordingly, a department for Innovation Research in Utility Sectors (Cirus) was established in 2005. Under Zehnder, sustainability and a transdisciplinary approach



A total of 458 people (including 26 apprentices) currently occupy 413 full-time equivalent positions; the proportion of women is 48.4 per cent.

were promoted, and a number of major projects were pursued in cooperation with partners from government, the private sector and academia. These included Greenhydro (environmentally sound hydropower, completed in 2000), Fischnetz (declining fish yields in Switzerland, 2003), Rhône/Thur (sustainable river management, 2005) and Novaquatis (urine source separation, 2006).

When Zehnder was appointed President of the ETH Board in the summer of 2004, his deputy Ueli Bundi (a rural engineer) became Director ad interim. Bundi emphasized in particular Eawag's role in bridging the gap between academic research and practice. In 2004, in partnership with the Swiss Fishery Association and the Federal Office for the Environment, Eawag set up the Swiss Fishery Advice Centre (FIBER). 2007 saw the launch of the "Water Agenda 21" initiative to promote a more integrated approach to water management issues in Switzerland. Bundi also supported preparatory work for the new Centre for Applied Ecotoxicology. Together with Roland Schertenleib and the team of architects from Bob Gysin & Partner, Bundi was one of the fathers of the new Eawag/Empa building Forum Chriesbach, which won several awards for innovative design and sustainability.

No contradiction between cutting-edge research and applications. Since being appointed Director in 2007, Janet Hering has intensified Eawag's cooperation with the EPF Lausanne and the ETH Zurich. As an ETH Board member representing the four research institutes (until 2010), she saw how important it was for Eawag to excel in research (as well as maintaining close contacts with water professionals) if it is not to be eclipsed by the much



1940



2010

Collecting plankton samples on Lake Lucerne (left) and surveying structural diversity on the Sense as part of the river assessment procedure developed by Eawag (right).

larger institutes of technology. Evolutionary aquatic ecology, analysis and ecotoxicology of micropollutants and transformation products, and the removal of these substances from wastewater are all gaps which Eawag is ideally positioned to fill.

The example of micropollutants also demonstrates that cutting-edge research and real-life application concepts can, and indeed must, be pursued concurrently. Eawag's work thus laid the foundations for the preparation in 2010 of an amendment to the Water Protection Ordinance, which provides for the removal of micropollutants at selected wastewater treatment plants.

Cleantech: a fitting aspiration. In the context of Cleantech, Eawag's commitment to the safety of water resources (in the interests of human health) and the protection of natural waters (in the interests of ecosystem health) is becoming increasingly important. For example, current wastewater treatment projects are no longer exclusively concerned with eliminating, as far as possible, all pollutants and nutrients; instead, the goal is to do so in such a way as to minimize energy consumption and emissions, while recovering valuable resources (see the article on page 30).

In addition, Eawag projects have always sought to ensure that the solution of one problem does not generate new ones. For example, when a ban on phosphates in detergents was being considered in the 1980s, Eawag researchers evaluated the phosphate substitutes EDTA and NTA. Other cases in point are the efforts to avoid potentially hazardous chloramines in drinking water disinfection or, more recently, to replace animal experiments in ecotoxicology by using passive samplers or computer models.

The findings of pioneering research of this kind can always be fed into consulting activities, since the private sector often lacks the necessary expertise, equipment, time and financial resources. In recent years, these activities have been further strengthened with the development and expansion of the Centre for Applied Ecotoxicology (together with the EPFL) and the establishment of the Competence Centre for Drinking Water (CCDW). ○ ○ ○

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Supplying arguments and explaining the bigger picture

Rural engineer Ueli Bundi contributed significantly to Eawag's development, and reputation, for many years. He joined the WHO International Reference Centre for Waste Disposal – based at Eawag – in 1972. He was a member of the Eawag Directorate from 1990, serving as Deputy Director from 2000 and Director ad interim from 2004 to 2006. Ueli Bundi is currently a member of the Steering Committee of the National Research Programme "Sustainable Water Management". Here, he looks back.

Interview: Andri Bryner

Ueli, you were at Eawag for over 35 years. So what are you taking with you to the desert island? The island isn't deserted at all! I made a lot of friends at Eawag, and those friendships were based on a shared passion for water. Now that's something personal, but it's one of the reasons we always managed to maintain an environment conducive to highly motivated and innovative work of high quality.

The chronicles talk about a "new era" beginning when Werner Stumm became Director in 1970. Is that true? Stumm never called into question what his predecessor Otto Jaag had achieved. But he realized that the time was ripe for new ideas. He called for a more intellectual approach to water protection and – accordingly – a new conception of Eawag's role. He saw the institute as a scientifically strong advocate for natural waters and promoted increasing internationalization and greater involvement in higher education.

Were the Directors Jaag, Stumm and Zehnder the only people who decisively shaped Eawag? Eawag had the good fortune to have a series of outstanding, long-serving Directors. That is a key success factor, but just as important over the years have been large numbers of highly motivated employees. Scientific influence is indicated by publications, and with practical applications there's the recognition you gain among professionals. In the support area, it's more difficult to measure. I don't know how Stumm could have run Eawag without his deputy, Hannes Wasmer. Or try and imagine where Eawag would be today without effective IT systems. Or the childcare centre: without the efforts of Arianne Maniglia, that would never have been successfully developed. The quality and continuity of our training activities and environmental concept are due to Herbert Güttinger. Those are just a few examples, the list could go on and on.

What were the personal highlights of your own scientific career? I'd like to mention the interdisciplinary River Ecology

Research institutes are ideal settings for inter- and transdisciplinary projects.

group established in the 1980s, which enabled us to address quantitative water protection quite early on. That was important preliminary work for the 1992 revision of the Water Protection Act and later for a sound assessment of the state of our rivers and streams. Or the transdisciplinary "Swiss nitrogen balance" project, where a team of scientists from academia and research institutes, along with consultants and representatives of the FOEN, FOAG and Swiss Farmers Union, developed (around 1995) a basis for national nitrogen strategies. It also took a lot of enthusiasm and perseverance to ensure that the new Forum Chriesbach building would be a model of sustainability. That sent out a clear signal that Eawag practises what it preaches as an environmental research institute.

Are there any areas where Eawag has been unproductive? I wouldn't say "unproductive", but there were some projects where we learned the hard way. We needed several attempts to develop our social science and ecotoxicology activities. Or the redefinition of our research priorities in the early 1990s, when people had such high expectations of inter- and transdisciplinary cooperation. Today, you'd have to say in all honesty that those



large-scale projects – for example, integrated water resource management on the Töss – were not that successful.

Why are these cross-cutting projects so difficult to handle?

We underestimated the complexity of networked projects. In addition, researchers have to make their mark in their own specific disciplines. Scientific funding mechanisms are still primarily monodisciplinary. But Eawag has learned to set up transdisciplinary projects more professionally. And that has benefited later projects, like Green Hydropower or “Fischnetz” (Declining Fish Yields). Above all, doors have been opened: where there used to be divisions, say between river engineering and water protection, we now have constructive cooperation – with the Hydraulic Constructions Laboratory at the EPF Lausanne, for example. Research institutes represent an ideal setting for inter- and transdisciplinary projects, which means they have a special responsibility in this area.

What else has changed? One of the many positive changes I would emphasize is the vastly increased presence of women. In the past, aquatic research was male-dominated. It’s almost amusing now to think back to the days when smoking was allowed everywhere. Because most of the “Technical Committee” members were smokers, all the proposals to ban smoking were rejected. That’s completely inconceivable today.

How would you explain the success of Eawag? It’s certainly due to the focus on water, continuity and consistently excellent people. Since Stumm’s days, the central task has been to understand processes, rather than getting bogged down in individual, “topical” problems. Closer links with higher-education institutions brought an enhanced scientific reputation and access to promising young researchers. The third factor is international integration. The worldwide renown of Stumm and Zehnder – and their networks – opened doors for Eawag scientists at all the leading institutes.

Another success factor, I would say, is the emphasis placed on integrated water protection and resource use concepts. Here, our “Gewässerschutz 2000” project was completed as early as 1980. Because in 1972, people had already realized that adequate water pollution control requires more than just building wastewater treatment plants.

Have these goals now been achieved, 30 years after the publication of the study? There has been major progress with water protection in Switzerland – for example, in terms of lake eutrophication, engineering measures in industry, or the catchment-based approach. But many advances are offset by growth and the emergence of new substances. For more than 30 years, the focus in the chemicals area has been on purely scientific approaches; ever-greater efforts are required to detect substances and their ecotoxicological effects. There’s a lack of convincing precautionary concepts for avoiding problems. Ethical



considerations should play a greater role in the production and use of chemicals. People now think the problems can be tackled with “end-of-pipe” measures – in the case of chemicals, by removing them at wastewater treatment plants.

What’s wrong with that kind of solution? I’m not saying that wastewater treatment measures aren’t necessary. But we must be careful to avoid creating the impression: “Problem solved – that’s all we need to do.” Even the most modern treatment plant never eliminates all pollutants. And besides, chemicals and heavy metals enter the environment by a variety of routes, not just via wastewater.

Millions of people have inadequate sanitation and no access to drinking water. Meanwhile, Eawag is analyzing micropollutant concentrations in the nanogram range. Is the institute tackling the real water issues? For me, this question doesn’t arise. Firstly, through Sandec, Eawag is actively seeking solutions to water problems in developing and transition countries. And secondly, aquatic chemistry is one of Eawag’s traditional strengths, and this strength should be maintained. That’s also true of other areas of expertise which in Switzerland are concentrated at Eawag – especially aquatic ecology and water treatment.

People often mention Otto Jaag’s successful efforts in the political arena. Is Eawag now apolitical? We have always actively influenced policy-making; simply by showing what fundamental changes of direction are needed and how they could be achieved. For example, with our 1974 study on the development of phosphorus pollution in Lake Greifen. We were promptly attacked for making statements like that – authorities and professional associations felt that we were “interfering”. Today, close links have been established with government, and contacts with other water stakeholders have improved. This ongoing “capacity building” is more important than anything else. Whatever the interests of specific user groups may be, Eawag must explain the bigger picture: what ecological services depend on water, how water affects society, and why we will always be dependent on certain qualities of water resources – for example, for clean drinking water, for agriculture or for diverse habitats and attractive landscapes. Historically, this high-level scientific endeavour has been at the heart of Eawag’s *raison d’être*. ○ ○ ○

Growing appreciation of the value of a precious resource

Janet Hering has been the Director of Eawag and Professor of Environmental Biogeochemistry at the ETH Zurich since 2007 and Professor of Environmental Chemistry at the EPF Lausanne since 2010. Here she explains how Eawag is pursuing the goals of “provision of water for human welfare and protection of water for ecosystem health”.

Interview: Andri Bryner

Janet, you’ve been the Director of Eawag for over four years now. What changes have you made so far? When I was deciding to come to Eawag, it was very attractive to me that no major changes were needed. Eawag was recognized worldwide for its outstanding research and facilities. Since the level of performance was already so high, I have been able to focus on the question of how our efforts could be directed strategically to increase synergies, advance our fundamental understanding of aquatic systems and address critical issues in society. I hope that the discussion I’ve encouraged will allow both Eawag and our researchers to set priorities and direct their resources accordingly.

Since our researchers, especially at the senior level, are the main drivers for Eawag’s success, I’m especially pleased that we continue to attract outstanding individuals as joint Professors with the ETH Zurich and EPF Lausanne and as Research Department Heads at Eawag. We have also attracted highly qualified individuals to lead our Support Departments, which is crucial to the success of our enterprise. I should also like to mention the Centre for Applied Ecotoxicology, a joint effort with the EPFL. The establishment of this centre was mandated by Parliament, and I feel that, with the cooperation of our EPFL colleagues, we have fulfilled this mandate very successfully.

How has the external environment changed? Like any institution, Eawag must respond to external changes to maintain its success. But some changes are also opportunities. In particular, there are increasing opportunities for international collaboration, for example in EU programmes with new member states. The broader range of opportunities makes it even more important to set priorities. We must also be careful that our national focus is maintained. Unfortunately, in parallel with increasing engagement with the EU, the level of bureaucracy has also increased. Although I strongly support accountability and expect it from my colleagues at Eawag, I think this should be embedded in a context of shared goals and motivation rather than control.



What problems do you see? I am most puzzled by the apparent lack of recognition of Eawag’s competitive advantages and the reluctance to take full advantage of them. Unlike our colleagues in most countries, Eawag researchers do not need to restrict their research agenda based on available external funding. Although external funding is certainly a consideration, we also have the resources to develop our own agenda. This can be more innovative, inter- and transdisciplinary, and ambitious than might be accepted by an external funding agency.

As an American, are you now acclimatized to Switzerland? I feel I’ve begun to understand the Swiss system of research and education and its underlying assumptions. I realize the importance of personal networks in this system, and I’ve started to develop my own networks here. Of course, I must also depend on my Eawag colleagues, particularly on the Directorate members and Research Department Heads, in this regard. I hope that I have been able to be effective on

Eawag’s behalf, but I realize that, for my colleagues, my approach is sometimes unconventional.

Switzerland’s lakes and rivers are now clean. Is there still a need for Eawag? Research carried out over the last 30 years has vastly expanded our knowledge of aquatic systems. Happily, it’s been possible to solve many problems – such as eutrophication of surface waters – at least in industrialized countries. But a lot of questions have yet to be resolved in Switzerland as well: Why are native fish populations disappearing? What are the best strategies for treating wastewater or the best measures for restoring near-natural river environments? We’re focusing in particular on the effects of micropollutants in water.

Even more pressing are the issues facing arid regions in developing and emerging countries, where people suffer directly from water scarcity and poor water quality. As a result of increasing degradation of the environment, aquatic ecosystem services can no longer be adequately provided, so there is a collapse in,

say, fisheries or the self-cleansing capacity of rivers. That represents both a challenge and an opportunity for research, as it can dramatically improve people's quality of life.

What can you do, as Director, to promote the achievement of these goals? As Director, I have the privilege of leading a large group of highly talented researchers and professionals who are dedicated to addressing these challenges. I support their efforts by seeking to ensure that their research environment is maintained and strengthened. In addition, I hope that we can further expand our collaboration at the national and international level. Rapidly developing countries like China or India offer excellent opportunities for applying the results of Swiss research and for exporting technologies. Eawag researchers have long been valued as experts by government and industry. We've enhanced our reputation with the Ecotox Centre and the Competence Centre for Drinking Water.

In Swiss water protection there are many questions we still need to address in cooperation with water professionals.

Adjunct, assistant and research professors based at Eawag
(for full professors see page 8).

	Field	Institution
Flavio Anselmetti	Sedimentology	ETH Zurich
Jürg Beer	Biogeochemistry and Pollutant Dynamics	ETH Zurich
Rik Eggen	Environmental Toxicology	ETH Zurich
Thomas Egli	Environmental Microbiology	ETH Zurich
Juliane Hollender	Environmental Chemistry	RWTH Aachen, ETH Zurich
Rolf Kipfer	Water Resources and Drinking Water	ETH Zurich
Hans-Joachim Mosler	Social and Environmental Psychology	University of Zurich
Peter Reichert	Systems Analysis and Modelling	ETH Zurich
Kristin Schirmer	Environmental Toxicology	EPF Lausanne University of Waterloo, Canada
Mario Schirmer	Hydrogeology	University of Neuchâtel
Hans-Ruedi Siegrist	Process Engineering	ETH Zurich
Laura Sigg	Environmental Toxicology	ETH Zurich
Bernhard Truffer	Innovation Research in Utility Sectors	University of Bern
Christoph Vorburger	Evolutionary Ecology	SNSF (ETH Zurich)
Urs von Gunten	Water Resources and Drinking Water	ETH Zurich (+ full professorship EPF Lausanne)
Lenny Winkel	Environmental Inorganic Geochemistry	SNSF (ETH Zurich)
Alfred Wüest	Aquatic Physics	ETH Zurich

How can scientific knowledge be transferred to professional practice? This is mainly accomplished by researchers cooperating directly with professionals – with water suppliers, wastewater treatment plant operators, engineers or manufacturers of chemicals and equipment. For inventions and spin-offs, we have an internal contact point which deals with patents, for example. But

knowledge transfer also takes place through education, and a lot of Eawag staff are involved in teaching – at the EPF Lausanne, the ETH Zurich, at Cantonal universities or universities of applied sciences. Since 2008, we've run a training programme for PhD students from developing countries. We regularly organize public events such as the Eawag Info Day and issue publications. Last but not least, Eawag contributes its expertise to legislative processes, for example on the question of limits for chemicals.

At the moment you're working on Eawag's Strategic Plan for the period 2012–2016. What are the key elements? We want to maintain and build on existing strengths in research, teaching and consulting – right across the spectrum from disciplinary to inter- and transdisciplinary projects. Another goal is to expand collaborations within the ETH Domain and with Cantonal universities, to keep developing international partnerships, and to make sure we have the best possible conditions so that Eawag remains attractive for outstanding scientists, nationally and internationally. We also intend to further develop our cooperation with professionals, especially through training and consulting – as in the case of the Centre for Applied Ecotoxicology or the Competence Centre for Drinking Water. In the natural, social and engineering sciences, we aim to lay the foundation to meet human needs for water while at the same time to preserve the aquatic environment and its indispensable services – in other words, the provision of water for human welfare and protection of water for ecosystem health.

How do you see the future for water? Direct human needs for water have been recognized by society throughout history, but we have only recently come to appreciate the ecosystem services provided by the water environment. I am optimistic that, in the future, we will increasingly appreciate the value of this resource and the importance of protecting it. We must foster technological innovation and societal adaptation so that pressures on the water environment associated with human activities are reduced without compromising human welfare. I hope that Eawag will remain at the forefront of this crucial effort. ○ ○ ○



Kristin Schirmer, biologist, is head of the Environmental Toxicology department.

Do transformation products pose environmental risks?

Technical and natural processes such as irradiation with ultraviolet light lead to the transformation of chemical substances in aquatic environments. But are environmental risks reduced as a result? Drawing on knowledge of transformation processes, and using chemical and biological analytical methods, Eawag is developing ways of answering this question.

Oxidative and photochemical processes play a key role in the degradation of organic compounds in natural waters or during water treatment. In general, however, such compounds are not immediately broken down to carbon dioxide and water (i.e. mineralized); instead, a mixture consisting of various transformation products arises. But normally, little or nothing is known about the identity of these transformation products – or potential risks to the environment.

In a study co-authored by Kathrin Fenner of the Department of Environmental Chemistry at Eawag [1], available data on the occurrence, behaviour and toxicity of a number of pesticides and associated transformation products in surface- and groundwater were analysed. The study showed that transformation products may be encountered more frequently than the parent compounds, and that they are often more persistent. In addition, transformation products are generally more mobile – in other words, they are usually less likely to bind to organic matter, e.g. in sediment. Finally, transformation products are often less toxic than the parent compounds.

Exposure-driven assessment approach. Certain transformation products, however, may be 10 or even 100 times more toxic than the parent compound. Oxidation products of diclofenac – an anti-inflammatory agent often found in surface water – are a case in point. A mixture of products formed when diclofenac is exposed to sunlight causes inhibition of algal reproduction several times greater than that seen with diclofenac itself [2]. There is thus no doubt that transformation products can contribute to the overall chemical burden in the aquatic environment, and that there is a need for careful assessment. But, given the multiplicity of possible series of reactions and resultant product mixtures, how can one determine whether substances of (ecotoxicological) concern are actually produced?

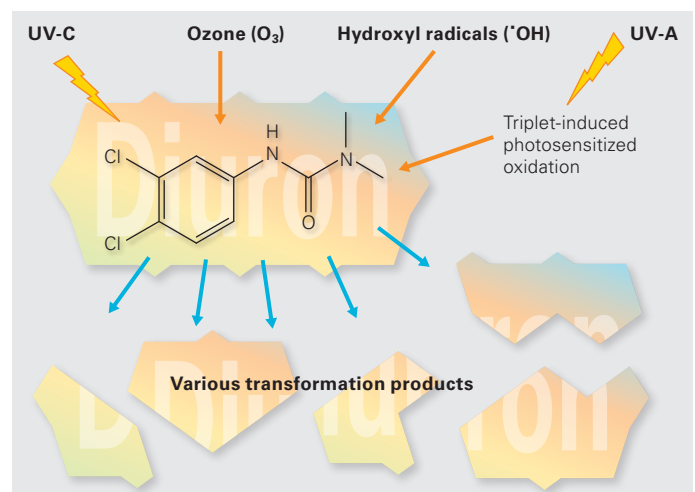
Two approaches may be used for environmental risk assessment of transformation products, based on the two components that define the risk – exposure and effect. An environmental risk only arises if organisms are in fact exposed to transformation products in the environment (exposure) and if these products pro-

duce a response in the organisms (effect). In assessing exposure, the questions to be considered are “What transformation products are formed?” and “What concentrations are detectable in the environment?”. The relevance of effects, on the other hand, is assessed by investigating the toxicity of transformation products relative to the parent compound.

Depending on the focus of the assessment, the approach adopted can thus be characterized as exposure-driven or effect-driven. In both cases, exposure and effect are closely linked, but there are differences in the line of attack and in the level of detail of the information obtained [3].

The exposure-driven assessment approach aims to identify transformation products in environmental samples by chemical analysis. If the analytical data indicate the presence of transformation products in relevant concentrations, these are then identified by fractionation and additional analyses. Ideally, a biological effect profile will already be available for the transformation products identified, or at least for structurally similar compounds. In most

Fig. 1: Effect-driven assessment approach for four transformation processes (diuron here stands for various parent compounds).



cases, however, it is to be expected that no such information exists as yet. Effect data then have to be obtained by subjecting the isolated or newly synthesized transformation products to biological testing.

Effect-driven assessment approach. The effect-driven assessment approach is based on the toxic potential of the parent compound and of the mixtures arising from transformation processes, as determined by biological testing. If, during transformation, the toxic potential of a mixture decreases in proportion to the disappearance of the parent compound, it can be assumed that toxicity is dominated by the parent compound, and the transformation products are not relevant for the environmental risk assessment. Only if the toxicity of the mixture is greater than would be expected for the parent compound are further steps required to identify the toxicologically active substance(s). This would include, for example, a combination of fractionation and biological and chemical analysis [4].

It is apparent that the exposure-driven assessment approach calls for major efforts, which do however provide a detailed account of the identity and toxicity of transformation products. In contrast, the effect-driven approach is more pragmatic and less costly and time-consuming, since the identity and toxicity of transformation products are only investigated if the effects differ from those expected for the parent compound. With both approaches, if chemical and biological analysis is to be effective, the list of possible transformation products needs to be narrowed down. Knowledge-based and computer-aided predictions concerning the identity and biological modes of action of expected transformation products are thus essential [5, 6].

Four-step procedure. In view of the large number of relevant substances and possible oxidative and photochemical transformation processes, the effect-driven assessment approach is currently being pursued by Eawag researchers Nadine Bramaz and Kristin Schirmer of the Environmental Toxicology department, and by Hana Mestankova, Urs von Gunten and Silvio Canonica of the Water Resources and Drinking Water department, in cooperation with Beate Escher of the National Research Centre for Environmental Toxicology (Entox) in Australia. They are focusing in particular on specific biological effects – e.g. inhibition of enzyme activity or of photosynthesis [7]. Specific effects of this kind generally occur at substance concentrations lying well below so-called baseline toxicity, which involves non-specific interactions with cell membranes. With the effect-driven approach, the evolution of toxicity is studied for four different transformation processes (Fig. 1) – direct phototransformation by ultraviolet radiation, triplet-induced photosensitized oxidation (based on photoexcitation of dissolved organic matter), oxidation by hydroxyl radicals, and by ozone.

For example, the researchers used the effect-driven approach to study the effects of the herbicide diuron on the unicellular green alga *Pseudokirchneriella subcapitata*. Diuron (3-(3,4-dichlorophenyl)-1,1-dimethylurea) is a specific inhibitor of photosynthesis and growth in plants. Because of its relevance in

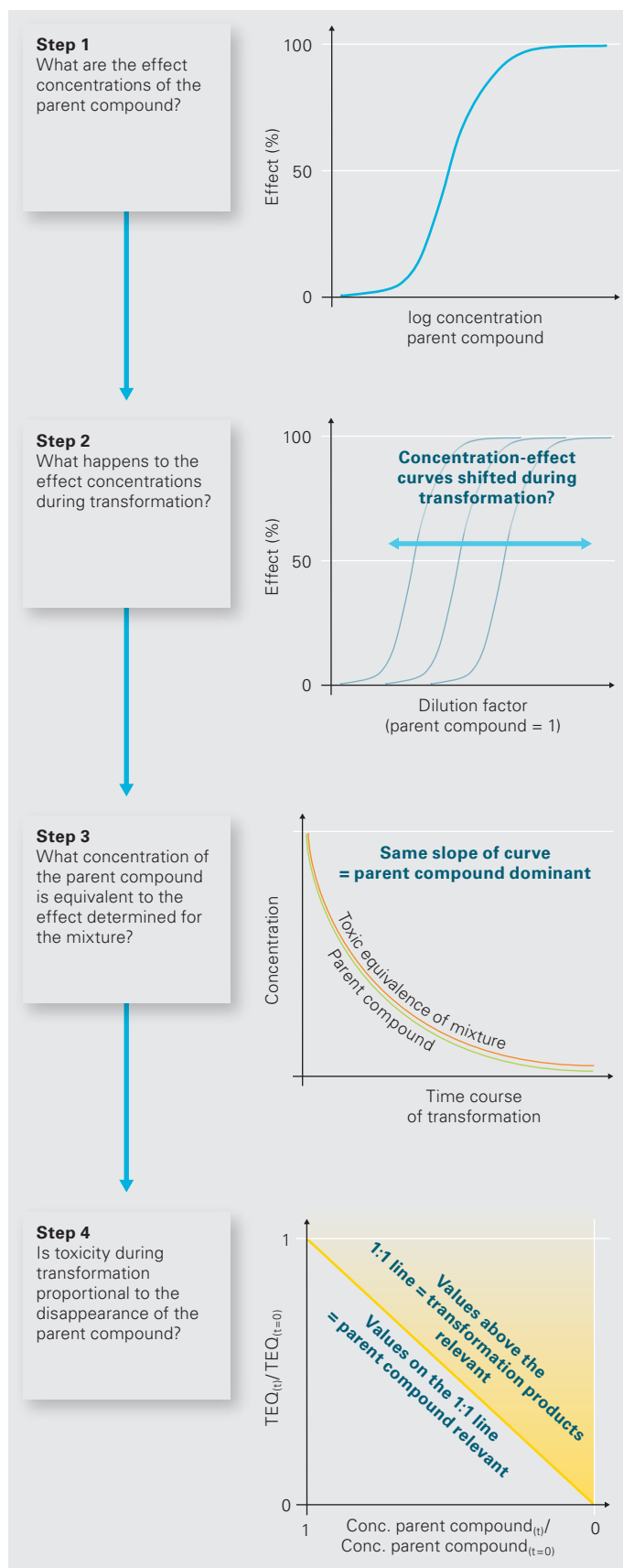


Fig. 2: The effect-driven assessment approach can be divided into four steps.

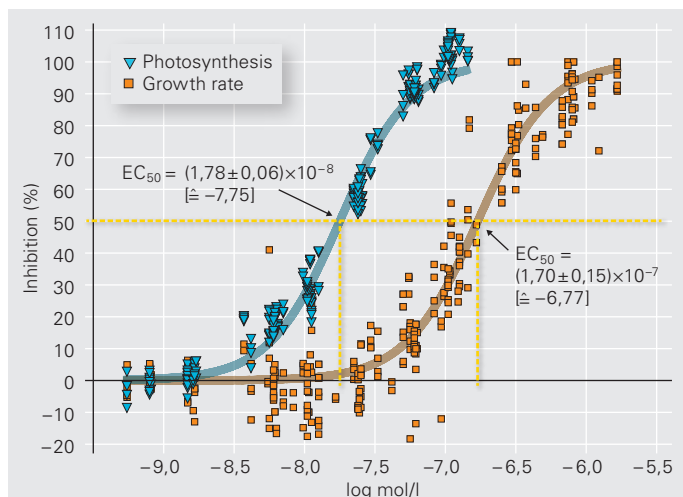


Nadine Bramaz and Hana Mestankova discuss the toxicity results for a mixture of parent compound and transformation products in a microtitre plate. Shown in the background is the chromatography system used to determine the concentration of the parent compound in the mixture.

ecotoxicology and ease of handling, the scientists selected this green alga as a typical photosynthetically active organism.

The effect-driven approach can be divided into four steps (Fig. 2). First, the effect concentrations of the parent compound are determined – i.e., in this case, inhibition by diuron of photosynthesis and algal growth. These concentrations subsequently serve as a reference for assessment of the mixture (see Step 3). The concentration of diuron which reduced the quantum yield of photosynthesis in *Pseudokirchneriella subcapitata* by 50 per cent after two hours' exposure (EC_{50}) was $1.78 \pm 0,06 \times 10^{-8}$ moles per

Fig. 3: Concentration-effect relationships for inhibition of photosynthesis and of the growth rate in the green alga *Pseudokirchneriella subcapitata*, as determined in a combined algae test [7, 8].



litre (mol/l); for inhibition of the algal growth rate over 24 hours, the EC_{50} was $1.7 \pm 0,15 \times 10^{-7}$ mol/l (Fig. 3).

In Step 2, the transformation processes – here, the four (photo-)oxidative processes shown in Figure 1 – are investigated. This involves determining the effects of the resultant mixtures (diuron and its transformation products) at various time points. Figure 4a shows how the concentration-effect relationships for inhibition of photosynthesis evolve when diuron is degraded by direct phototransformation. As concentrations can no longer be assigned to a specific compound, the EC_{50} is expressed as a dilution factor (dilution factor = 1 for initial concentration of diuron). The figure shows that the concentration-effect curves shift towards higher concentrations with increasing photodegradation; inhibition of the photosystem thus decreases over time.

Are transformation products relevant? In Step 3, to allow effects of mixtures to be compared with those of the parent compound, the concept of toxic equivalent concentrations (TEQs) is employed [8, 9]. This involves dividing the EC_{50} for the reference compound (i.e. diuron) by the EC_{50} for a given mixture; the resultant diuron equivalent concentration (DEQ) indicates the concentration of diuron to which the effect observed for the mixture is equivalent. If the toxicity of the mixture is dominated by the reference compound alone, then the biologically determined DEQs should evolve in line with the chemically quantified diuron concentrations. This pattern was in fact observed with direct phototransformation of diuron (Fig. 4b).

In Step 4, the ratio of the DEQs over time from the bioassay to the initial DEQ value is plotted against the ratio of the analytically quantified diuron concentrations over time to the initial diuron concentration. If the biological effects of the mixture are determined by diuron alone, the decrease in DEQs is expected to be proportional (1:1) to the decrease in diuron concentrations. If the mixture of transformation products is more toxic than the reference compound, the values will lie clearly above the 1:1 line (Fig. 2, Step 4). As Figure 4c shows, the former is the case for direct phototransformation of diuron. Inhibition of photosynthesis and of the algal growth rate is thus dominated by the action of diuron. It may be concluded that for this combination and this test system no further studies are required with regard to ecotoxicological assessment of transformation products. Similar findings were obtained for the other three (photo-)oxidative processes investigated.

Validation and further development. Given the variety and complexity of the mixtures of transformation products expected to occur in the environment, step-by-step assessment of ecotoxicological risks would appear to be advisable. We propose that the method described above should be adopted as an effective first step in determining whether transformation products show greater toxicity than the parent compound from which they are formed, or whether the ecotoxicological risk can be assessed on the basis of the parent compound alone.

We are currently using this approach to study transformation products formed by (photo-)oxidative degradation of triclosan (an

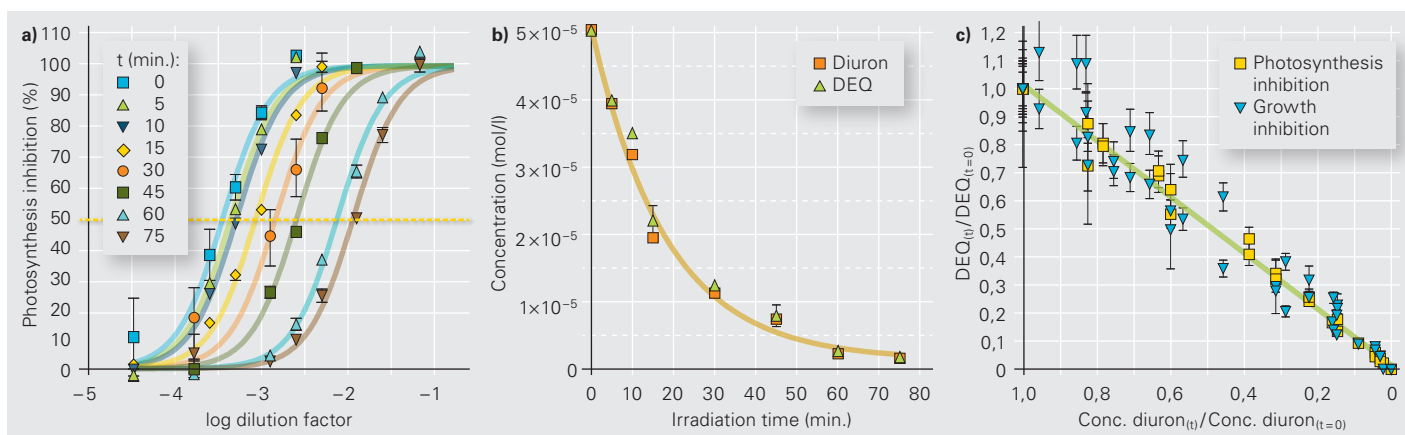


Fig. 4: Effects on the green alga *Pseudokirchneriella subcapitata* observed with diuron and transformation products formed by direct phototransformation of diuron. a) Direct phototransformation of diuron (50 $\mu\text{mol/l}$, pH = 8) produces mixtures of transformation products which show decreasing inhibition of photosynthesis with increasing irradiation time. b) Diuron equivalent concentrations (DEQ) decrease in line with diuron concentrations during irradiation. c) The fact that the biological effects (inhibition of photosynthesis and growth rate) are proportional to diuron concentrations at any given point indicates that they are predominantly caused by diuron in the mixture of transformation products.

antibacterial agent) and oseltamivir (the active ingredient of the antiviral drug Tamiflu). In another project, supported by the US Water Research Foundation, we – together with colleagues from the University of Colorado – are studying substances included in the US Environmental Protection Agency's list of priority drinking water contaminants. These studies will contribute to a science-based assessment of the limits and opportunities of (photo-) oxidative transformation processes with regard to protection of drinking water and of the aquatic environment. At the same time, they will help to validate and further develop the methods described. The greatest challenge lies in identifying possible toxic effects which cannot be straightforwardly predicted from the chemical structure of the parent compound or from known biological modes of action. ○ ○ ○

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Drinking water microbiology: from understanding to applications



Frederik Hammes, environmental microbiologist, works in the Drinking Water Microbiology and Ecophysiology group in the Environmental Microbiology department.

Good-quality drinking water contains a wide variety of naturally occurring microorganisms. In fact, microbial processes play an important role in drinking water treatment. However, water quality can be adversely affected by contamination with pathogenic bacteria. New methods permit improved monitoring of drinking water – and a better understanding of fundamental microbiological processes.

Although bacteria are a natural constituent of drinking water, consumers generally have negative perceptions of these unseen and largely unknown organisms. This is at least partly due to the fact that certain waterborne bacteria are pathogenic. In recent years, for example, thousands of people in Haiti and Zimbabwe have died of cholera, a disease caused by the bacterium *Vibrio cholerae*. In addition, uncontrolled bacterial growth can impair the taste, odour or colour of drinking water and cause turbidity.

But the vast majority of microorganisms in drinking water are completely harmless. Indeed, microbial processes are an essential functional component of drinking water treatment. For example, many treatment plants use biological filtration (e.g. granulated active carbon or slow sand filtration) to remove unwanted organic compounds from water [1].

Biological stability. A fuller understanding of microbial diversity, ecology and related processes in drinking water will therefore help to improve the management of treatment and distribution systems, promoting a safer final product for consumers. The ultimate goal is not only to produce drinking water of high quality but to ensure that this quality is maintained in the water reaching consumers' taps. To prevent excessive bacterial regrowth during transport and residence in the distribution network, chlorine or chlorine dioxide is added as a disinfectant in some countries. However, this may have undesired consequences because, as well as inactivating pathogens, chlorine reacts with organic matter in drinking water, forming various toxic by-products [2].

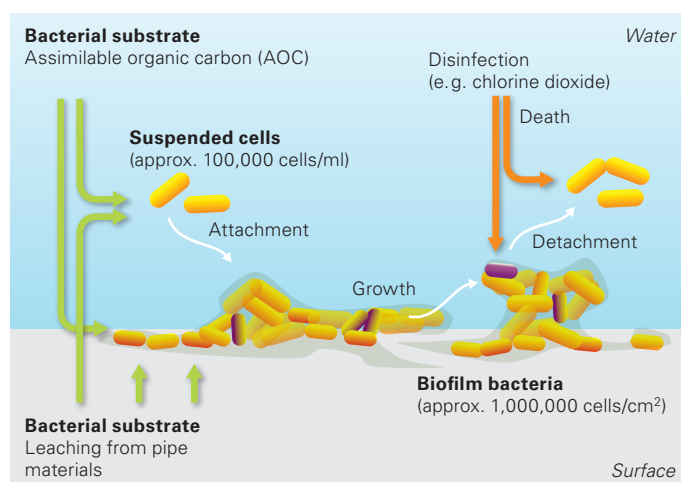
Switzerland and numerous other European countries such as Germany, Austria and the Netherlands wish to avoid the use of additional chemicals as far as possible and, alongside chlorination, already rely on the production of biologically stable water in many distribution systems. This approach involves a combination of scientific knowledge, engineered applications and experience. The goal is to prevent bacterial growth in the distribution system by controlling nutrient levels, since growth rates depend on the

substrate available in the form of organic carbon (e.g. sugar, amino acids or organic acids). Competition between different microorganisms for the available substrate also limits the reproduction of individual species, contributing to a dynamic balance (Fig. 1).

If the microbial quality of drinking water is to be reliably monitored, analytical methods are required which can determine parameters such as available substrate and bacterial biomass.

Determining pathogen growth potential. Measurement of available nutrients is a reliable way of estimating the potential for bacterial growth in drinking water. As organic carbon is usually the growth-limiting substrate, nearly all water utilities routinely

Fig. 1: Bacterial dynamics in a water distribution system. The bacteria mainly utilize assimilable organic carbon (AOC), i.e. the fraction of dissolved organic carbon which can be readily consumed by microorganisms, leading to growth. AOC is therefore considered to be a key parameter governing the total number of bacteria and the microbiological stability of drinking water.



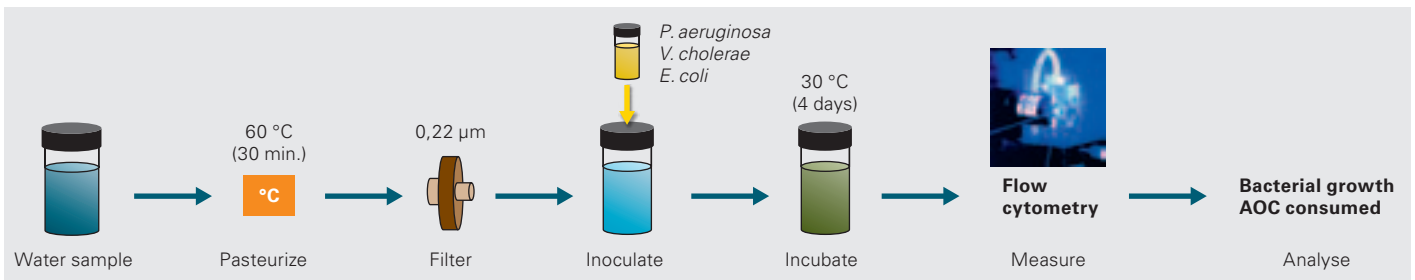


Fig. 2: The basic steps of the PGP assay (adapted from [4]).

measure concentrations of dissolved organic carbon (DOC). Drinking water appears “clean” with DOC concentrations in the range of 0.5–2 milligrams per litre. In fact, microorganisms only utilize 1–10 per cent of the DOC. This proportion, known as assimilable organic carbon (AOC), is thus the key parameter in drinking water treatment [3]. Even trace amounts of organic carbon can lead to unwanted bacterial growth – as little as 0.001 milligrams is sufficient to produce 10,000,000 bacterial cells.

As well as measuring AOC concentrations, it is important to judge the biologically available substrate from a hygienic perspective. Eawag has therefore developed a method to specifically assess the fraction of AOC that pathogenic bacteria grow on [4].

This is based on the fact that different bacteria have widely different nutrient preferences and degradation capabilities. Using the pathogen growth potential (PGP) assay, it is possible to determine directly whether and to what extent a water sample can support the growth of specifically selected bacteria, such as *Escherichia coli*, *Vibrio cholerae* or *Pseudomonas aeruginosa* (Fig. 2).

The application of this method is not limited to drinking water, as shown by extensive tests on surface water and wastewater samples. Figure 3 illustrates changes in the growth potential of pathogenic and indigenous bacteria during drinking water treatment, compared to treated wastewater. Here, biological filtration significantly reduces the PGP – with only minor growth potential

Fundamental microbiological processes in drinking water systems are not yet fully understood. Photo: Microbial diversity in the biofilm of a drinking water biofilter.



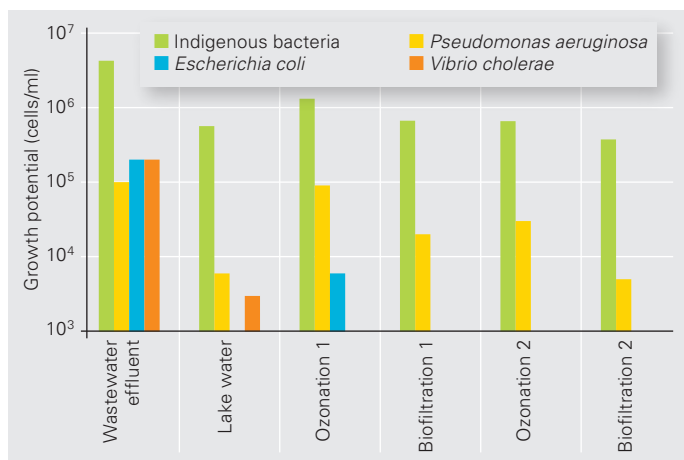


Fig. 3: Growth potential of pathogenic and indigenous bacteria during drinking water treatment, compared to values for wastewater effluent (adapted from [4]).

remaining for *Pseudomonas aeruginosa* – as the available organic carbon substrate is consumed by indigenous biofilter bacteria.

The PGP assay not only makes it possible to assess the quality of water sources and evaluate the results of treatment technologies. It also allows for research into the nutrient requirements of specific bacteria and the competition between pathogenic and indigenous bacteria for available resources.

Counting intact and damaged cells. A millilitre of treated drinking water typically contains between 20,000 and 200,000 bacterial cells, depending on the water source and type of treatment. Accurate information on concentrations of bacterial cells in drinking water has both scientific and practical relevance: changes in cell concentrations indicate microbial processes occurring in the water, which can affect its quality.

Complementing the PGP assay are methods which permit direct measurement of cell concentrations. The consumption of AOC can be demonstrated by an increase in cell concentrations. Such measurements are particularly suitable for assessing the microbiological stability of drinking water during distribution.

Over the last few years, Eawag has developed analytical methods involving flow cytometry and measurement of adenosine triphosphate (ATP), which could replace conventional cultivation-based methods as they are considerably more rapid and accurate [5, 6]. These two complementary approaches can be used to describe the microbial quality of a broad range of water samples, including groundwater, drinking water, bottled water, surface water and wastewater (Fig. 4).

The evaluation of disinfection processes (e.g. ozonation or chlorination) requires methods for the determination of viable cell concentrations.

When combined with a staining method, flow cytometry can also provide information on the activity or viability of microorganisms in drinking water. In her doctoral thesis, Maaïke Ramseier used this approach to measure the disinfection effi-

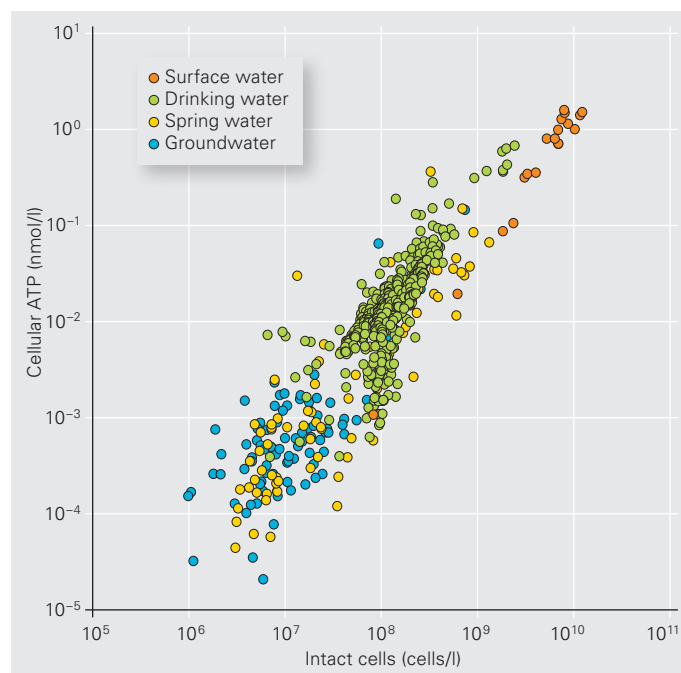
cacy of a number of oxidants – ozone, chlorine, chlorine dioxide, monochloramine, ferrate and permanganate [7]. Oxidants cause severe damage to bacterial cell walls, and because membrane-compromised cells are selectively stained by propidium iodide they can be distinguished from intact cells when flow cytometry is subsequently performed. In a tap water sample treated with chlorine dioxide (Fig. 5), bacterial damage as a function of time (exposure) is clearly visible.

By looking at specific cellular features (in this instance membrane integrity), the flow cytometric approach not only demonstrates the efficacy of the disinfection process but also partly explains the underlying mechanism. Flow cytometry coupled with staining methods thus offers scientists an analytical tool for investigating and elucidating the disinfection kinetics of bacteria.

The method also enables water utilities to assess disinfection processes directly on site, thus allowing an immediate response in the event of malfunctions or changes in water quality. The ability to distinguish between damaged and intact cells also permits the monitoring of distribution systems where chlorination is used: since this disinfection step damages all cells at the point of treatment, the presence of intact cells in such a system is a clear indication of bacterial growth – and hence the failure of chemical network protection. This is of major relevance in Switzerland, where more and more waterworks are considering a changeover from chemical protection to biological stability.

This approach has already been applied successfully in case studies in the cities of Basel, Zurich, Riga and Amsterdam, with all

Fig. 4: Correlation between bacterial cell counts (determined by flow cytometry) and ATP concentrations in a variety of water samples. Depending on the source, water samples show characteristic ATP concentrations and cell counts (data from [6] and from Stefan Koetzsch).



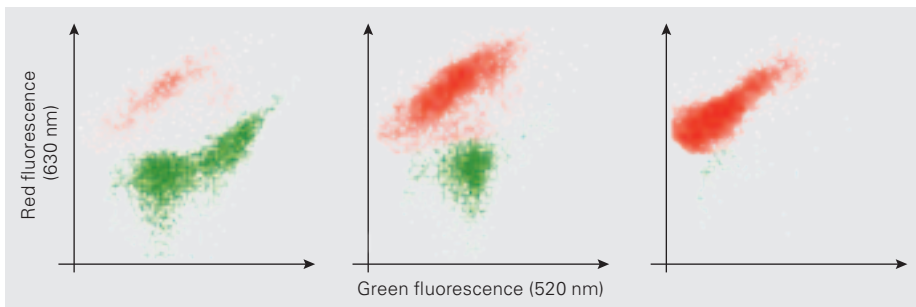


Fig. 5: Flow cytometric analysis used to distinguish damaged from intact bacterial cells in water: cells stained in red by propidium iodide are damaged, while those in green (not specifically stained) are intact. Damage is increased from left to right as a function of exposure (adapted from [7]).

these water utilities now employing variations of this method for either research or monitoring purposes.

Better understanding of mechanisms. The diversity of the microbial world is well documented: there are 52 recognized bacterial phyla, and an estimated 1–10 million bacterial species, covering a broad range of physical properties, nutritional requirements and physiological states [8]. While much of this diversity was suspected for many years, the tools for detecting and characterizing microorganisms in detail have remained limited.

However, recent advances in high-throughput sequencing methods now make it possible to identify thousands of organisms from a small water sample. In a study carried out by Eawag and the University of Illinois, a technique known as pyrosequencing was used to analyse the microbial diversity of non-chlorinated drinking water. This method allows in-depth analysis of the microbial community structure in a sample by sequencing the 16S rRNA genes of bacteria. We were thus able to identify different groups of microorganisms and to determine their relative abundance.

The first practical outcome of the study – apart from a long list of bacterial names – was that microbial community analysis could be used as a tool to determine the stability of drinking water in a distribution system [3]. It was possible to detect small changes resulting from bacterial growth or contamination and to identify the specific organisms responsible. High-quality drinking water remains essentially stable as regards cell concentration and microbial community composition from the point of production to the point of consumption.

A detailed understanding of microbial communities in drinking water treatment systems will lead to an understanding of their functional value. Currently, while we know that biological filters are operationally sound processes, they are essentially “black box” environments with regard to the composition and characteristics of their active agents (bacteria). It is foreseen that a deeper knowledge of the microbial communities will facilitate optimal design and operation of such biological filters.

In the future, increasing water demand due to global population growth will place greater pressure on water resources, and environmental changes (e.g. climate change) will also increase the need for water-quality monitoring and control. To meet these challenges, careful planning and a better understanding of microbiological processes in water distribution systems will be essential.

The development of a broad range of methods in drinking water microbiology enhances our fundamental understanding of microbial behaviour in these man-made environments. These methods and the knowledge generated by their application in turn provide water utilities with the tools required to further improve treatment processes and to guarantee sustainable provision of high-quality drinking water. ○ ○ ○

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Wastewater management



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Strategic planning of urban water infrastructure

Sustainable strategic planning of Switzerland's drinking water supply and wastewater management infrastructure has to take future demand and uncertainties into account. Rather than aiming to reduce costs as far as possible, sound solutions seek to optimize benefits over the entire lifespan and are adapted to local conditions. There is no "one-size-fits-all" solution for the country as a whole.

Switzerland's drinking water supply and wastewater management systems are key elements of its public-sector provision. Thanks to targeted investments over the years, the country now has a safe and effective nationwide water infrastructure, providing high-quality services. The wastewater management sector alone comprises a sewer network with a total length of around 87,000 kilometres, 759 centralized and 3500 small treatment plants, and approx. 30,000 pretreatment facilities. The estimated replacement value of Switzerland's water supply and wastewater management infrastructure is CHF 218 billion; this does not include recurring imputed costs of around CHF 8 billion per year [1].

Planning for the future today. To ensure that available resources in the water supply and wastewater management sector are deployed cost-effectively over the long term, it is necessary to begin planning for the future today and to take strategic decisions on the development of urban water management. To this end, there is a need to identify the operational and political factors which significantly influence the urban water management system. In particular, all the uncertainties which are inevitably involved in strategic planning need to be assessed, as far as possible, and integrated into decision-making in a transparent manner. Here, researchers have a special responsibility to make appropriate methods available for the development of realistic future scenarios and the evaluation of new approaches.

For example, it is important to know for costing purposes whether a system shows economies (or diseconomies) of scale – in other words, whether it becomes relatively less (or more) expensive with increasing size. Also to be investigated are the costs of uncertainties taken into account in the planning process.

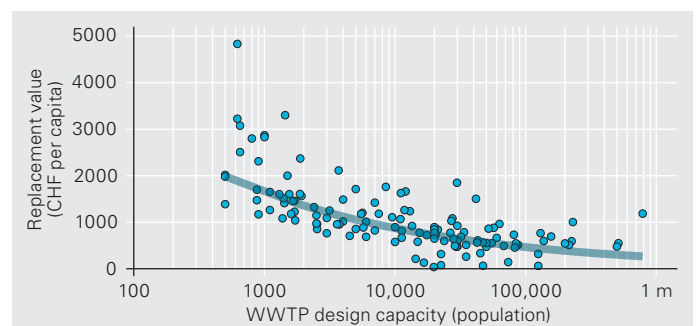
Are large plants really less expensive? At first glance, wastewater (WWTPs) and drinking water treatment plants seem to show marked economies of scale: if the size of a plant is doubled, the costs are increased by only 60–70 per cent. Large plants thus appear to be relatively less expensive. Calculations indicate that the replacement costs for Swiss WWTPs designed to serve a population of 100,000 are on average 3.5 times lower per capita

than for plants serving a population of 1000 (Fig. 1). Comparable economies of scale can also be demonstrated for WWTPs in other countries and for drinking water treatment systems [3]. The reduction in costs due to economies of scale is currently one of the main arguments used to support the combination of WWTPs into centralized systems.

However, larger systems require a larger sewer network. Considered in their entirety, do such systems still show economies of scale? To answer this question, we developed a mathematical model which, on the basis of settlement data from Federal Statistical Office land use statistics, represents the dimensioning of combined sewer infrastructure in Switzerland [4]. In this model, population and building density and catchment area size are used to estimate the length and replacement value of the sewer network for a settlement. In addition, the model can be used to determine the most important quantitative factors affecting construction costs for combined sewer systems.

Essentially, three factors are relevant: the pipe diameter, the proportion of impermeable surfaces, and the population and building density. Larger settlements have more extensive sewer networks, necessitating a larger pipe diameter which in turn increases construction costs. In addition, they generally have a

Fig. 1: Economies of scale seen in the replacement value of Swiss WWTPs. The replacement value in Swiss francs per capita is shown here as a function of design capacity for 128 plants. As design capacity increases, the costs per capita are reduced. [2]





In the water supply and wastewater management sector, efforts are currently focused on preserving the value of existing infrastructure. But there is also a need for tools to assess future requirements.

higher proportion of impermeable surfaces, i.e. a lower runoff coefficient. This means that more stormwater has to be drained via the sewer network, leading to an increase in design capacity and higher costs. However, costs will be reduced with a higher population and building density, as they are distributed among a larger number of inhabitants.

No clear economies of scale. While pipe diameter and impermeable surface area are clearly associated with *diseconomies* of scale – costs rise disproportionately as size increases – population and building density show economies of scale. In Switzerland, these various factors balance out: in other words, the replacement value, statistically, is not relatively lower (or higher) in larger settlements. Overall, therefore, the Swiss sewer network does not show economies of scale (Fig. 2).

As the construction costs for a WWTP amount to only 10–20 per cent of those for a sewer network, it can be concluded that for Switzerland’s wastewater management systems as a whole (sewerage and WWTPs) there are no clear economies of scale: the construction costs for larger systems may – but need not – be lower. This means that assigning wastewater management to a small number of centralized plants does not necessarily lead to lower costs. The planning of new systems, therefore, calls for a flexible approach. In particular, such planning needs to take into account possible future scenarios for settlement structures (e.g. sprawling development or growth). Sparsely settled areas with uncertain future prospects, in particular, are disproportion-

ately cost-intensive. In regions of this kind, a decentralized wastewater treatment system could be the better option.

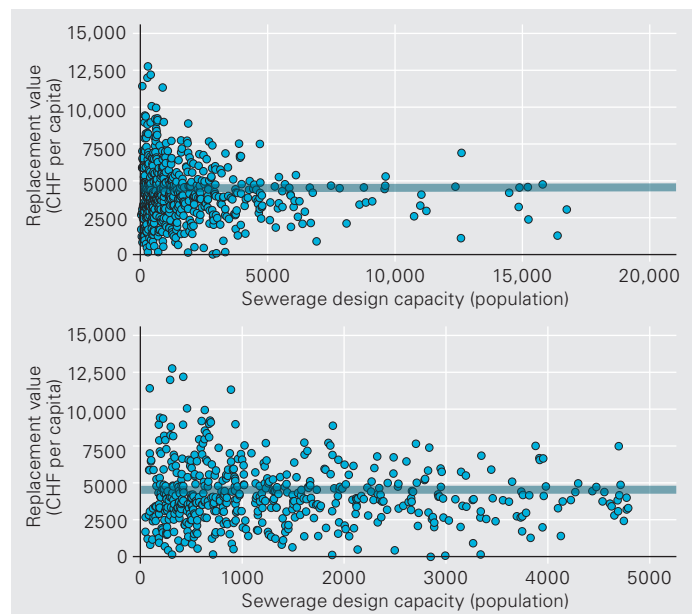
Considering uncertainties in the estimation of costs. Infrastructure represents a long-term investment, which also needs to satisfy the requirements of the future. For example, treatment plants are designed and constructed on the basis of predictions of how demand will develop over the next 30 years. With the deterministic planning approach which is generally used, it is assumed that demand will grow at a certain rate and capacity is specified in such a way that plant utilization will be 100 per cent at the end of the plant’s lifespan – i.e. it will be able to meet projected demand throughout its service life.

Obviously, however, any analysis of the future involves uncertainties. As a result, a plant may in fact be unable to meet demand before it reaches the end of its lifespan, or the predicted capacity utilization may never be attained. Either under- or oversizing will lead to additional costs. Of relevance, here, are not only the production costs (total plant construction costs) but also the per-capita costs arising throughout the period of operation.

Using a method developed by our group, it is possible to quantify in monetary terms the effects of planning uncertainties [5]. With this approach, we can model all possible developments of demand and calculate the costs per user in each case. In addition, different weights are attached to the likelihood of occurrence of the various scenarios. The extent to which expected demand can vary when uncertainties are taken into account is demonstrated by the hypothetical example given in Figure 3.

According to our model, costs per user are mainly determined by the growth rate and uncertainty of demand: for example, the

Fig. 2: Replacement value of combined sewers in Swiss settlements. The costs per capita are not reduced as design capacity increases – i.e. there are no economies of scale. [2]



greater the extent and duration of overcapacity, the lower the average capacity utilization over the plant's service life. In Figure 3, the average load is 66 per cent. Compared to a solution where growth does not have to be taken into account, the lifetime costs are thus 34 per cent higher than would be required on the basis of actual demand.

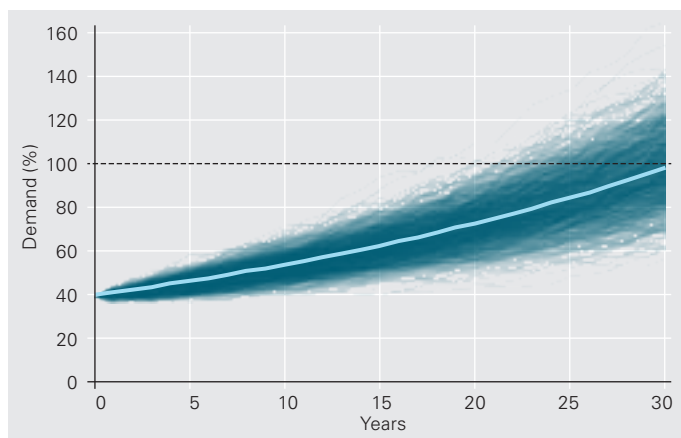
Our method also makes it possible to assess the probability of costs being considerably higher than expected. In the example shown in Figure 3, the costs will be more than 34 per cent higher in 80 per cent of cases and more than 49 per cent higher in 10 per cent of cases (not visible in the graph). The reference value for costs is always taken to be the average construction costs per user with the plant operating at full capacity and without any uncertainties.

From this perspective, flexible solutions which can be adapted to growing demand in a modular fashion may now prove to be superior and ultimately less expensive than would appear from a conventional cost comparison method which takes neither demand growth rate nor uncertainties into account.

Regional Infrastructure Foresight. To ensure sustainable development of water infrastructure, investment decisions need to be based on an integrated planning process. Rather than focusing on reducing construction costs as far as possible, sound solutions will seek to optimize benefits over the entire lifespan. To support this planning process, Eawag is participating in two National Research Programmes sponsored by the Swiss National Science Foundation – “Sustainable Development of the Built Environment” (NRP 54) and “Sustainable Water Management” (NRP 61).

In “Regional Infrastructure Foresight” (RIF) – a project, now completed, which formed part of NRP 54 – we collaborated with

Fig. 3: Expected demand, with uncertainties taken into account, in a hypothetical scenario. The thick curve represents an expected increase in plant utilization of 3 % per year according to a deterministic approach. Plant utilization would thus reach 100 % after 30 years. If demand remains consistently below this curve, the plant is oversized and the costs are higher than predicted. In contrast, if plant capacity is exceeded before the end of the lifespan, the plant is undersized; the costs are then also higher than predicted. The thin curves represent various possible development scenarios, taking uncertainties into account. [5]



key policymakers in elaborating a strategy for the regional development of urban water management [6]. We identified important pointers by which more detailed decisions should be guided. Essentially, RIF comprises two central elements:

► **Future scenarios:** a wide variety of developments are postulated for the most important factors influencing the urban water management sector. They represent the future under different economic conditions – ranging from explosive growth to serious decline – and provide a basis for evaluation of the various options available.

► **Available options:** with the aid of a systematic overview, possible options are explored for the development of local drinking water supply and wastewater management. These include both technological and organizational aspects, e.g. increasing catchment area size or comparing centralized versus decentralized treatment systems.

On the basis of policymakers' goals, the various options can now be independently evaluated for all future scenarios. This makes it possible to select the option which is both preferred by policymakers and as robust as possible with respect to the various future scenarios.

In a case study involving the Kiesen and Aare Valley in Canton Berne, for example, it was shown that a “shoulder-to-shoulder” strategy should be pursued for wastewater treatment, with an organizational merger of the region's WWTP associations. The strategy selected yielded medium to high desirability for policymakers with regard to all future scenarios and thus turned out to be the most robust option. All other options received a low rating for at least one scenario and exhibited lower robustness.

Sustainable Water Infrastructure Planning. The “Sustainable Water Infrastructure Planning” (SWIP) project (part of NRP 61) quantifies the effects of specific options and management approaches, and compares these with the goals of all stakeholders. For example, greater expenditure on repairs could reduce the risk of burst pipes, thereby preventing disruption of services. The question then arises whether stakeholders are prepared to make greater investments or whether they prefer to accept more frequent disruptions.

With case studies carried out in a number of communes, the planning process is to be optimized and specific planning measures are to be developed for water supply and wastewater management infrastructure. The project seeks to balance economic (predicted costs), environmental (ecosystem impacts) and social aspects (stakeholder values).

Special attention is paid to the fact that many Swiss communes lack precise data on infrastructure and that future developments cannot be predicted with certainty. SWIP is based on existing planning instruments such as the General Wastewater Management Plan (GEP) or General Water Supply Plan (GWP), which identify defects in communal infrastructure and propose investment plans.

Alongside the regional RIF and SWIP approach, we are currently investigating trends and knowledge gaps at the national level. According to the preliminary “Water Supply 2025” study,



The Mönchaltorf WWTP (Canton Zurich) is one of the plants involved in the SWIP project, which aims to optimize the planning process and develop specific planning measures for the water supply and wastewater management infrastructure of various communes.

the security of Switzerland's drinking water supplies is assured in the future. However, the report identifies a need for further research, e.g. concerning the impact of climate change on raw water quality and structural requirements for a sustainable water supply system. The relevant publications and recommendations are available on the Eawag website [7]. Work on the "Wastewater Management 2025" study is to be completed in the autumn of 2011, and the report will also be published online.

No "one-size-fits-all" solution. While in practice efforts are currently focused on preserving the value of existing infrastructure, there is a need for methods to facilitate the assessment of future requirements. This is essential if Switzerland's urban water management services are to be maintained and optimized over the long term.

A sound basis is required for decision-making on the technologies and systems to be used in the future. It is also important and advisable to include radically new concepts such as decentralized systems in the evaluation process. Thanks to technological advances, decentralized approaches in particular represent an attractive option for the future [8]. A more detailed account of these systems is given in the article on page 30.

Unlike mere value preservation, which calls almost exclusively for technical expertise, sustainable strategic planning has to consider fundamental questions and the needs of all stakeholders. Whether responsibility for wastewater treatment should be assigned to a neighbouring commune, or whether a communal enterprise should be converted into a joint-stock company (AG), are typical organizational questions arising in the course of strategic planning. In a case study in the Klettgau region (Canton

Schaffhausen), for example, the original question raised was how the WWTP was to be expanded; but other options were then considered, including a merger with a neighbouring WWTP in Germany and complete decentralization of wastewater treatment.

In summary, strategic planning for the Swiss urban water management sector needs to combine two different questions: *How* can existing structures be further developed and *in what direction* should this development proceed? The results to date clearly indicate that there is no "one-size-fits-all" solution for the country as a whole. Instead, what is needed are solutions optimally adapted to local conditions. ○ ○ ○

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Combined efforts to improve sanitation

One of the main causes of diarrhoea and high infant mortality in developing countries is poor sanitation. The challenge for applied research in this field is to develop technological and planning solutions which are adapted to local conditions. This can only be achieved by collaborating closely with NGOs, local communities and the authorities.



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While the attention of international public health experts is largely focused on Aids, malaria and tuberculosis, one condition which may appear to be harmless – diarrhoea – actually kills more young children worldwide each year than these three diseases combined. With reliable sanitation and safe drinking water, however, around 2.4 million deaths could be prevented annually. Such deaths mostly occur in children when diarrhoea is associated with subsequent malnutrition and other diseases attributable to malnutrition [1].

Safe disposal of faeces and improved hygiene would be effective ways of preventing the spread of pathogens and associated diarrhoeal diseases (Fig. 1). For a large proportion of the global population, therefore, sanitation is the priority concern in the wastewater management sector.

Planning with, not just for, the community. With the adoption of the Millennium Declaration in 2000, UN member states launched a global initiative to combat poverty. In the area of environmental sustainability, one of the Millennium Development Goals is to halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation.

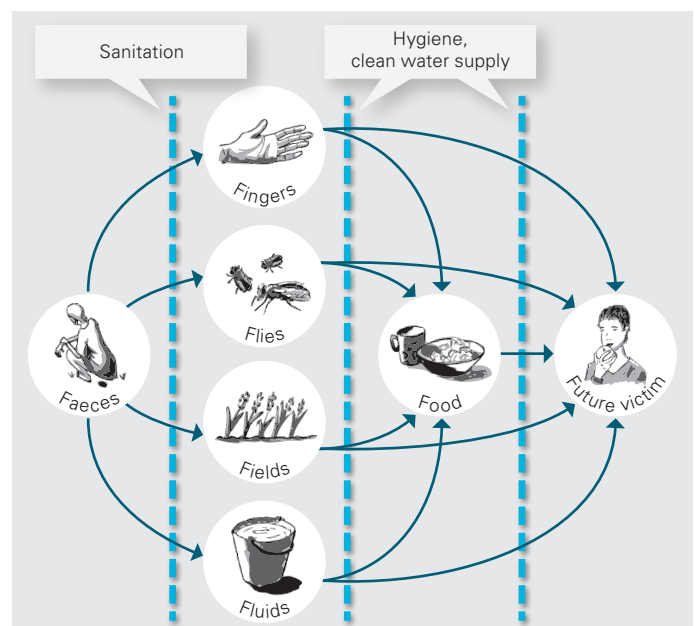
While this goal is easy to formulate, realization is an extremely complex matter. With the world's population expected to rise to more than 9 billion by 2050, the urban population growing at almost twice the rate of the overall population, and the proportion of slum dwellers in the cities of developing and transition countries averaging 30–50 per cent, there is a need for innovative approaches – not only in terms of the technologies chosen, but also in planning, financing, implementation and sustainable operation. Here, applied research needs to make major efforts to support practitioners and policymakers with locally adapted solutions.

When urban wastewater systems are designed in developing countries, planners and engineers generally decide what type of infrastructure and services should be available. Often, the technological solution proposed is a sewer network with a wastewater treatment plant on the European model, irrespective of local needs and possibilities. In most cases, the public is not involved in the planning process, but remains the passive recipient of a system provided by the authorities.

However, for understaffed, underfunded municipal waste management organizations in developing countries, it is scarcely possible to operate and ensure the maintenance of a European-style sewer network. In addition, a network of this kind cannot be expanded sufficiently rapidly to keep pace with urban growth, and capacity problems will arise sooner or later in the main lines and at the treatment plant. And what happens if water is a scarce and expensive commodity, and long-term access to water supplies is by no means assured? In such cases, a waterborne sewage system will soon collapse.

If individual urban districts are to be provided with reliable wastewater services despite such difficulties, alternative, more flexible approaches need to be envisaged – with the involvement of the local community and small businesses. It was already ap-

Fig. 1: Routes of faecal disease transmission and protective barriers. Improved sanitation can prevent transmission at source, while a clean water supply and improved hygiene can reduce the spread of infection.





Residents of Hatsady Tai – a low-income district of Vientiane, the capital of Laos – constructing new wastewater infrastructure.

parent from the UN's first International Drinking Water Supply and Sanitation Decade (1981–1990) that the participation of users in planning and development is generally essential to the long-term success of infrastructure schemes [2].

Participatory planning approach. Against this background, an approach which places individual households at the centre of the planning process was developed several years ago in an Eawag research project. The key idea is that direct participation of the community lays the foundations for a collective sense of ownership and responsibility, thereby promoting sustainable solutions. In cooperation with local organizations and authorities, Christoph Lüthi and his colleagues sought to validate this approach with the aid of pilot studies in seven urban neighbourhoods in Kenya, Tanzania, Laos, Nepal and Costa Rica.

Hatsady Tai, for example, is a typical low-income settlement near the centre of Vientiane (the capital of Laos): many of the buildings were constructed illegally on public land, and 14.5 per cent of the population suffer from diarrhoea, largely as a result of poor sanitation. Together with the Public Works and Transportation Institute (a government agency) and representatives of the local community, our group spent 18 months developing an overall plan for improving sanitation in Hatsady. This process included an assessment of current environmental sanitation services and of user priorities, the identification of options to improve sanitation, a joint evaluation of possible solutions and the elaboration of waste management plans.

The implementation process took another four months. Existing cesspits were renovated and converted into sedimentation chambers to improve the removal of solids. These chambers were connected to a solids-free sewer system, with liquid waste undergoing anaerobic treatment in septic tanks. A private service provider assumed responsibility for faecal sludge management

(collection from cesspits for centralized treatment at the municipal plant).

In addition to wastewater management measures, it was important to improve stormwater drainage and solid waste collection in this flat, low-lying area. In particular, the project promoted household waste sorting and separate collection of different types of waste.

The residents of Hatsady Tai played an active part in the entire planning process. Most of them attended meetings and hearings, and three households made available part of their land for the construction of community septic tanks. A number of households also accepted alterations to their properties to allow for the construction of drains.

Most of the community took an active part in the planning process for improved sanitation in Hatsady Tai.



As a result of the project, sanitation in Hatsady Tai has been significantly improved. For example, flooding has become less frequent thanks to the new stormwater drainage system, and municipal waste is now rarely burnt within the neighbourhood. Consequently, there has been a reduction in smoke nuisances and respiratory disorders. Above all, however, the local community has learned from this experience that it is not solely dependent on the goodwill of the authorities, but can successfully take action itself to improve the quality of its environment [3].

Based on the experience gained from the various pilot projects, planning guidelines have now been developed for decision-makers in developing countries: "Community-Led Urban Environmental Sanitation" offers a complete set of tools, with detailed guidance on each step of the planning process. Particular attention is paid to low-income regions, where improvement of sanitation remains a highly complex undertaking.

Advantages of decentralized solutions. In many large cities in Asia and Africa, less than 20 per cent of households are connected to a sewer network. In smaller towns, sewerage is generally completely lacking [4]. However, almost all urban households have on-site sanitation facilities: pit latrines or septic tanks are

Flooding is now less common in Hatsady Tai thanks to the new stormwater drainage system.



used for liquid/solids separation. These are periodically emptied, and the faecal sludge is then disposed of. Such facilities should be integrated into wastewater management plans.

In developing countries, decentralized disposal facilities usually also offer economic advantages, as shown by a study carried out in Senegal. For the city of Dakar, researchers from Eawag and the University of Cheikh Anta Diop (Dakar) compared the costs of a conventional sewer network and centralized wastewater treatment plant with those of decentralized faecal sludge collection and centralized treatment: the investment costs are 11 times higher for the former than for the latter. Even the maintenance costs are twice as high for the centralized system. In order to operate a system of this kind, the government waste disposal authority levies wastewater charges which are payable by the whole population – including households not connected to the sewer network. If charges were only payable by households which actually have a connection, the revenues would only cover 20 per cent of the operating costs.

However, even though decentralized faecal sludge management is significantly less expensive, this system cannot currently be implemented in Dakar in such a way as to cover costs either. In many cases, faecal sludge is collected by private companies using vacuum tankers. But – given the population's limited means – the fees charged are set at such a low level that they barely cover the costs of emptying and transport. To reduce costs, therefore, companies often dispose of faecal sludge in an environmentally unsound manner – on fields, at dumps or in rivers.

Faecal sludge – a valuable resource. Although the disposal of faecal sludge is common practice worldwide, surprisingly little wastewater research is devoted to this topic. Activated sludge treatment plants, which have been extensively studied, or waste stabilization ponds adapted to local conditions in developing countries are rapidly overloaded if they have to deal with large quantities of highly concentrated faecal sludge, and they are not suitable for further treatment of this product.

For over a decade, Eawag has been collaborating with universities and research institutes in developing and transition countries in efforts to develop appropriate faecal sludge treatment technologies. Various systems, such as settling ponds, co-composting and planted or unplanted drying beds, have been tested and investigated in depth in Ghana, Senegal, Cameroon, Thailand and Vietnam. The last of these approaches appears to be particularly promising, but the appropriate process can only be determined in the local context.

As well as highlighting process-engineering challenges in faecal sludge treatment, the studies have shown that more attention should be paid to faecal sludge as a potential resource. Given the exhausted soils typical of peri-urban intensive agriculture, there could well be a demand for the organic matter and nutrients. If products of faecal sludge treatment are commercially viable, sanitation could also become attractive for local businesses – which in turn would promote the expansion of wastewater treatment.

Some steps have already been taken in this direction. For example, in a project in Yaoundé (Cameroon), Eawag researchers



Creating value: antelope grass grown on dried faecal sludge can be sold as a forage plant.

and colleagues from the University of Yaoundé showed that indigenous antelope grass (*Echinochloa pyramidalis*) can be grown in planted sludge drying beds. Antelope grass is popular among livestock farmers as a forage plant because it is superior to wild grass in terms of nutrient content [5].

Another promising way of creating value from faecal sludge for local businesses derives from a project which was originally concerned with organic solid waste. With a pilot treatment unit set up in Costa Rica, Stefan Diener of Sandec demonstrated that organic waste can be processed using larvae of the black soldier fly (*Hermetia illucens*). The larvae rapidly degrade the organic matter, developing into prepupae as they feed. Consisting of 40 per cent protein and 30 per cent fat, the prepupae represent a sustainable alternative to fishmeal, which is currently used in the animal feed industry. In addition, they are easy to harvest since they crawl out of the waste as soon as they reach the prepupal stage. Because fishmeal prices have risen dramatically, this product could become an increasingly attractive source of income [6].

Initial studies carried out by Eawag and the Asian Institute of Technology in Bangkok indicate that the method is also effective when dried faecal sludge is used. Larvae were fed on dewatered sludge (water content: 63 per cent) from septic tanks mixed with market waste in different ratios. Although with higher proportions of faecal sludge the larvae grew less rapidly and gained less weight, they developed well and contributed significantly to the reduction of faecal sludge. Further studies will now investigate whether and how the larvae kill pathogens in the sludge.

Bridging the gap between research and practice. Research in the sanitation field is increasingly developing alternative approaches and technologies which are particularly suitable for use in developing countries. But local stakeholders – entrepreneurs,

experts, planners, and decision-makers in municipal authorities – also need to be able to access this knowledge so that it can be adapted and applied to specific local contexts.

This kind of knowledge transfer is no easy matter. Eawag seeks, firstly, to involve local stakeholders as far as possible in early project stages and, secondly, to reach out to practitioners and policymakers with the aid of short films, handbooks or learning materials, as well as the usual scientific publications. Rather than addressing local stakeholders directly, it is often useful to engage in partnerships with key organizations within the country concerned or with international NGOs or development agencies. These include the Swiss Agency for Development and Cooperation (SDC), which not only has a long history of supporting research, but also incorporates the results of research into its own projects or disseminates them via its local cooperation offices. This means that research can serve as a vital interface between innovation and practice and, by developing new approaches, play its part in improving sanitation and combating poverty. ○○○

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Cleantech for wastewater treatment of the future

In wastewater treatment, environmentally sound and resource-efficient technologies should also exploit the resources contained in wastewater itself. Radically new approaches such as urine source separation and the recovery of nutrients for urine-based fertilizers point the way to a future which goes beyond conventional sewers and wastewater treatment plants.

The Federal Council's Swiss Cleantech Masterplan is designed to promote technologies that help to preserve natural resources and the environment. As well as relieving pressure on the environment, the initiative aims to strengthen the capacity for innovation and the country's export industry. In the research sector, the Masterplan calls for expansion of the cleantech knowledge base and improvement of knowledge and technology transfer between higher education institutions and industry (<http://www.cleantech.admin.ch/cleantech>).

Eawag has long been concerned with the question of what forms resource-efficient wastewater treatment could take, and where markets for such technologies exist. We have now started to develop solutions of this kind and to seek industrial partners for commercialization.

Resources in urban water management. In recent years, Eawag's research in the field of resource-oriented urban water management has been largely shaped by global resource issues since, comparatively speaking, Switzerland's drinking water supply and wastewater disposal systems are of a high standard and its surface waters are of excellent quality. However, in addressing global issues, the goal has also been (and still is) to find solutions that are less costly and offer greater benefits for Switzerland as well [1].

Key ideas referred to in the Cleantech Masterplan, such as sustainable use of resources, efficient processes, limited environmental impact and cost-effectiveness are also applicable to the urban water management sector. But compared to the production

Fig. 1: In the development of sustainable technologies for urban water management, various kinds of resources need to be taken into account.

In wastewater	In wastewater treatment
Water Energy Nutrients, etc.	Energy Chemicals, etc.
Natural	Anthropogenic
Receiving waters Soil Atmosphere, etc.	Capital Institutions Acceptance, etc.



Tove A. Larsen, chemical engineer, works in the Urban Water Management department and (with Judit Lienert) was a co-leader of the Novaquatis project.

of goods, the requirements for sustainable environmental technologies are more complex: the aim is not only to optimize the use of resources in wastewater treatment, and its cost-effectiveness, but also to exploit the resources contained in wastewater and to protect natural resources such as receiving waters and the atmosphere (Fig. 1). To date, unfortunately, most approaches have focused on just one part of the wastewater system, while ignoring the other aspects. What is needed, however, is a shift away from this sectoral way of thinking towards a holistic approach, encompassing the optimization of all areas and resources. Only then can we claim to be developing sustainable technologies.

Inadequate nutrient removal. The conventional "end-of-pipe" approach is based on the drainage of mixed wastewater from households and industry via the sewer network and subsequent treatment at centralized plants. In recent years, numerous problems associated with this approach have been identified. For example, a great deal of wastewater research in this area has been concerned with the removal of nutrients at wastewater treatment plants (WWTPs) in order to avoid eutrophication of surface waters due to discharges of nitrogen and phosphorus. However, a recent study demonstrates that, from a global perspective, nitrogen and phosphorus removal efforts are inadequate, with a very small proportion of these nutrients actually being removed from wastewater (Fig. 2). This is likely to remain the case in the coming decades. Although the authors estimate that the capacity of WWTPs to remove nutrients will increase fourfold from 2000 to 2050, this is by no means sufficient to deal with the rise in nutrient inputs to wastewater driven by population growth and changes in diet. Using model calculations, they showed that the resultant nitrogen and phosphorus emissions from wastewater will almost double over this period. Building WWTPs and sewer networks is a costly and lengthy enterprise – and often impossible in practice, especially in rapidly expanding urban areas.

Increased water scarcity in future. The Cleantech Masterplan assumes that, owing to climate change, many resources could become scarce in the future. This is particularly true of freshwater. For example, depending on the climate scenario, experts predict



Urine-diverting dry toilet: the innovative technology used for the facilities in Durban (South Africa) is only visible on closer inspection.



eThekweni Water Services

that between 3.2 and 4.6 billion people worldwide will be affected by severe water stress (<1000 m³ available per capita per year) in 2020, with the total rising to 4.9–6.9 billion by 2050 [3]. For comparison, around 1.6 billion people currently live under these precarious conditions, while in Switzerland 6500 m³ water is available per capita per year at present.

Experts are already discussing how the challenges of water scarcity can be met. One instructive study from Australia examines the implications for energy use in the provision of water supplies in 2030 [4]. If increased water demand arising from population growth is met with the aid of technologies such as seawater desalination or wastewater recycling, primary energy use in the water supply sector could increase, at worst, by up to a factor of

5, to more than 200 watts per person. This development would not, of course, be compatible with the vision of the 2000-watt society adopted, for example, by the city of Zurich.

Increased water efficiency would thus appear to be essential. If the current level of water consumption in Australia were halved – from 300 to 150 litres per capita per day – existing water resources would still be sufficient in 2030. Initial experience suggests that such reductions are possible. Industrial and residential users – also in Switzerland – are making significant progress in increasing water efficiency.

Corrosion due to lack of water. However, conventional wastewater management, as practised in industrialized countries, re-

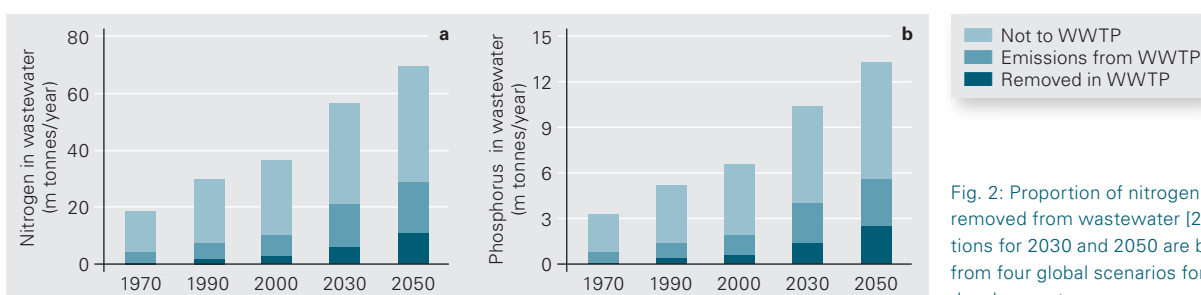


Fig. 2: Proportion of nitrogen (a) and phosphorus (b) removed from wastewater [2]. The authors' predictions for 2030 and 2050 are based on mean values from four global scenarios for future socioeconomic development.



In the laboratory, process engineer Kai Udert is testing various reactors for the removal of nutrients and contaminants from urine.

quires large amounts of water. For example, a minimum flow is needed in sewers to allow substances in wastewater to be reliably transported to WWTPs.

A striking illustration of what can happen when insufficient water flows through a sewer network is provided by experience in Phoenix, Arizona [5]. Here, owing to water shortages, water was diverted from sewers for reclamation, leaving solids to accumulate within the system. As a result, the concentrated wastewater became anaerobic, causing hydrogen sulphide to form, as is also known to occur in pressurized pipelines. The gaseous hydrogen sulphide reacted with oxygen on dry sewer walls to form sulphuric acid, leading to extensive corrosion damage.

Today, to ensure that sewers remain functional even with low water levels and to prevent corrosion damage, nitrate is sometimes added to wastewater. However, as well as increasing operating costs, nitrate dosing only intensifies the adverse effects caused by the already high levels of nitrogen pollution from wastewater and agricultural sources, and inadvertently creates new problems (e.g. in the denitrification process at the WWTP) [6].

The question thus arises whether, in regions which may become water-stressed, there is any point in building a sewer network if it may never function properly because of a lack of water.

From urine to fertilizer. What alternatives are available? With the Novaquatis project, Eawag has been working for some time on radically new wastewater treatment concepts, designed to address the various aspects of resource scarcity [7]. These are based on the separation of wastewater streams at source (see Box). With this approach, it is easier to integrate resource-efficient processes – e.g. for recovering nutrients or reducing water use – than with the mixed-wastewater, end-of-pipe system.

As with all fundamental changes to a well-established system, it will take time for these new ideas to be widely adopted. At

present, demand for these technologies exists mainly in areas where resources are already scarce and a waterborne sewage system along Western European lines is not an option – for example in some suburbs of Durban (South Africa).

Here, based on the experience gained through Novaquatis, Eawag is collaborating with the local service provider (eThekweni Water and Sanitation) and the University of KwaZulu-Natal on the VUNA nutrient harvesting project (www.eawag.ch/vuna). In the Durban region, a large and rapidly growing section of the population does not have connections to a sewer network with a centralized WWTP. For this part of the population, wastewater management in future is to involve dry toilets, with urine source separation. In addition, the nutrients nitrogen, phosphorus and potassium are to be extracted from urine in small reactors and used to produce a fertilizer. At present, urine seeps into the ground unused, threatening the safety of water supplies from a nearby lake.

The treatment being developed by VUNA project leader Kai Udert consists of biological nitrification (oxidation of part of the ammonium in urine to nitrate), followed by evaporation. The product of this process is a urine-based fertilizer composed of ammonium nitrate and other active fertilizer components (phosphorus and potassium). Although the project was only launched a short time ago, it is already clear that the technology works in principle in the laboratory and can be used to produce a fertilizer. How the system can be implemented in practice will become apparent in due course.

The process already has a reasonable energy balance, although there is still room for optimization before it can compete with large-scale treatment plants (Table 1). However, while the costs of such plants would be prohibitive in poor regions, solar power could well be used to meet the energy requirements of small-scale decentralized systems.

Success dependent on cost-effectiveness. But ultimately it will be the cost-effectiveness of the process that determines whether the technology is actually deployed. For this reason, VUNA re-

Urine source separation for nutrient recycling

Technically, urine source separation is a simple concept: for example, with a special “NoMix” toilet, urine can be separately drained and collected. Because urine accounts for most of the nutrients found in wastewater, separate urine treatment can replace the entire process of nutrient removal at the WWTP. In addition, with a concentrated solution, nutrients can be processed so as to produce fertilizers, helping to close the nutrient cycle. The opportunities and risks of this technology were investigated in detail in Eawag’s Novaquatis project.

www.novaquatis.eawag.ch

	Nitrogen (N)	Phosphorus (P)	N + P
Energy value of fertilizer	-5.2	-0.34	-5.5
Energy for wastewater treatment (large plant)	-5.2	-0.57	-5.8
Energy for nitrification (small reactor)	2.1		9.0
Energy for evaporation (85 % energy recovery)			20.0
Total (watts per person)			17.7

Table 1: Energy balance for nitrification and evaporation of urine (primary energy in watts per person). It is assumed that 1.5 l urine with 10 g nitrogen and 1 g phosphorus is produced per person per day [8]. Energy savings are expressed in negative terms.

searchers are investigating whether the nutrients recovered from urine provide a significant economic incentive to use and maintain the sanitation facilities. For example, on the basis of rough estimates, the monetary value of nutrients recovered from urine appears initially to be low, but it is significant compared to the costs of wastewater treatment in developing countries (Table 2). This estimation is however subject to substantial uncertainties. Firstly, there is wide variation in global market prices: while prices were stable and very low at the beginning of the last decade, recent years have seen major price fluctuations, mainly reflecting increased demand. In addition, nitrogen in the form of ammonium nitrate is twice as expensive as it is in the form of ammonia. Secondly, given the lack of data on nutrient excretion in Africa, European data had to be used.

From a technical viewpoint, efforts in the VUNA project are currently focused on product safety. According to analyses carried out at the Fraunhofer Institute in Munich, the fertilizer product has similar properties to pure ammonium nitrate – which is thermally unstable. Its stability is further reduced by sodium chloride residues and organic contaminants. As the urine-based fertilizer contains less than 28 per cent nitrogen, it would in fact already comply with Swiss and EU regulations. Nonetheless, Eawag is seeking to further improve the thermal stability by removing organic substances and possibly also sodium chloride from the product. This would also make the fertilizer easier to store and prevent possible adverse effects of pharmaceutical residues and sodium chloride in agriculture.

Table 2: Rough estimate of the monetary value of the nutrients nitrogen, phosphorus and potassium in urine (in US cents per person per day in Africa). Assumptions: 10 g nitrogen, 1 g phosphorus and 2.5 g potassium are excreted in urine per person per day; the retail price is 2.7 times the global market price (after [9]).

	2000 (Low)	2011 (Q1)	2008 (Peak)
Nitrogen (N)	0.97	2.3	5.8
Phosphorus (P)	0.16	0.58	1.0
Potassium (K)	0.14	0.51	1.1
Total (US cents)	1.3	3.4	7.9

For both nitrification and evaporation, contacts have been established with companies interested in developing and producing appropriate reactors. This suggests that the potential of urine source separation and associated nutrient recycling is now also – slowly but surely – being recognized in practice. Of particular relevance for the time being are those international markets where the demand for innovative wastewater management solutions is greatest. But at some point, approaches of this kind may also be seriously contemplated in Switzerland. In this country, we are in the meantime waiting for more mature NoMix toilets which would allow pilot projects to be conducted on a larger scale in private households. A concrete development project is now under way in the sanitary industry. ○ ○ ○

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Think globally, act locally

The major challenge facing aquatic environmental sciences today is to restore freshwater ecosystems so that the services they provide are maintained for future generations. In these efforts, local populations are of fundamental importance, since processes occurring at the local level underlie the functioning of ecosystems.

Freshwaters are among the most endangered ecosystems worldwide. This is also true for Switzerland, where river alterations, intensive land use and environmental pollution have changed the character of surface waters to such an extent that natural freshwater ecosystems have virtually disappeared. Additional pressures are associated with climate change, which is likely to bring rising average temperatures, seasonal water shortages and more frequent extreme weather events.

Diversity = adaptability. With regard to the protection and enhancement of freshwater habitats, the following key questions arise for aquatic ecologists: To what extent can ecosystems adapt to and compensate for environmental change? At what spatial scale are restoration and management measures effective? How long is the time lag between restoration and recovery? What are the priorities for allocation of limited management resources? In order to answer these questions, we need to understand local processes at the population level in particular. These are of fundamental importance to ecosystem functioning, as all relevant ecological and evolutionary processes take place within local populations. A population is defined as a group of individuals that reproduce together. While it is often difficult to see where one population ends and the next begins, the methods of ecological genetics can be helpful here.

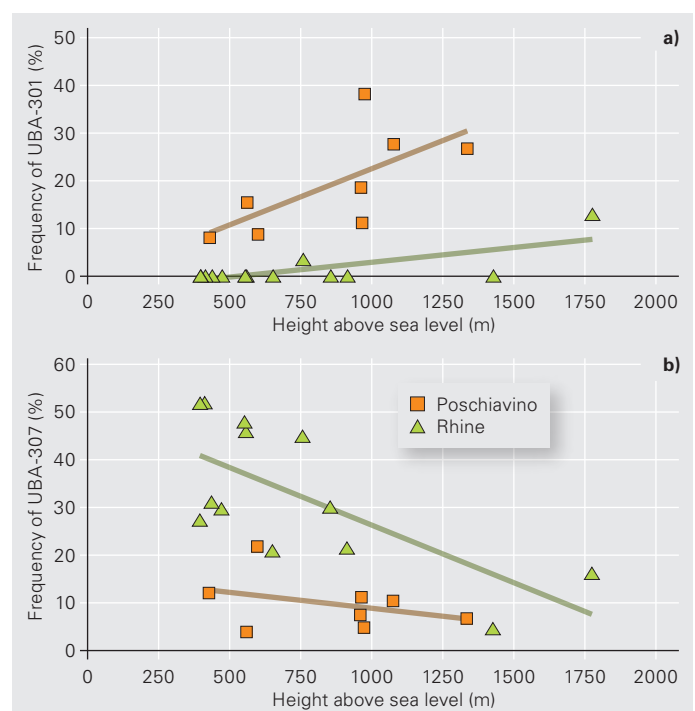
Ecological and genetic variability can help local populations – to a certain extent – in adapting to changing environmental conditions and in withstanding stressors. They thus help to preserve ecosystem stability and to assure the provision of ecosystem services. For this reason, the maintenance of local diversity should be a core concern of contemporary conservation biology. This approach rejects ecosystem conservation as an attempt to preserve the past, promoting instead the evolutionary dynamics which can support adaptation to new conditions.

Adaptation to altitude in fish. In measuring the genetic population structure of several groups of freshwater organisms in Switzerland, Eawag researchers have found that populations can show high levels of genetic differences even over short distances. In other words, for many key organisms, Switzerland has important

local races and much of this variation has been unknown until recently.

Genetic drift (see Glossary) and natural selection are two evolutionary mechanisms which can cause local populations to differ in their genetic composition. Additionally, environmental conditions and ecological interactions varying on a small spatial scale may lead to local adaptation. One striking example of local adaptation comes from recent research carried out by Eawag scientists on brown trout (*Salmo trutta*) in Switzerland [1]. High-elevation populations were found to possess genetic variants – lacking in low-elevation populations – which seem to be advantageous for

Fig. 1: Altitudinal adaptation in brown trout (*Salmo trutta*) populations of two Swiss drainage basins. With rising altitude, the frequency of the genetic variant UBA-301 increases (a), whereas the frequency of the genetic variant UBA-307 decreases (b).





Val Roseg (Canton Graubünden) is a typical habitat for the alpine caddisfly (*Allogamus uncatatus*). Populations live in temporary or permanent streams of alpine headwaters.

life at higher altitudes. This pattern was detected in several catchments across Switzerland, indicating that the brown trout have adapted to environmental parameters that correlate with altitude (Fig. 1).

The example shows that local environments may produce novel and unique local genetic variation. It is therefore essential that restoration efforts should seek to preserve such variation because this is what is needed for adaptation to environmental change. Genetic differences among local populations should also be taken into consideration in stocking measures.

Modern genetic techniques have made it possible for biologists to discover such cryptic biodiversity. Such examples of local adaptation may become more common as we gain more and more knowledge on genetic differences among local populations. This information should be used to improve management protocols in conservation measures.

Recolonization supported by population networks. Each species consists of many local populations which are connected to varying degrees, forming networks in which migrants are exchanged. For example, populations of fish in the same watershed are more likely to belong to the same network of populations than those in another watershed. Such networks of populations are called metapopulations.

Lisa Shama, Karen Kubow and Chris Robinson investigated metapopulations of the common alpine caddisfly *Allogamus uncatatus* [2, 3]. These caddisflies occupy small pools of flowing water in alpine headwater streams. The species overwinters as larvae, undergoing several larval instars before a winged adult emerges in the autumn, and active dispersal becomes possible. Each valley can have tens of more-or-less isolated populations in permanent and temporary sections of the stream. In detailed genetic studies, the researchers examined the long- and short-term history of the population networks in several valleys of Cantons Graubünden and Valais in order to understand the effects of the exceptionally hot summer of 2003, when even permanent streams dried up. The analysis of a gene region which only changes slowly in the course of evolution indicated five strongly diverged *Allogamus* groups in the different valleys (Fig. 2). The geographical pattern and the genetic signature of these metapopulations suggested that, after the glaciers of the last ice age had retreated, the valleys were colonized by individuals from different glacial refugia, resulting in the distinct genetic identities of the different valleys [2].

To reconstruct the more recent demographic history, the researchers also used genetic markers that provide a higher resolution of recent events than a conserved gene region. The data provided clear evidence of contemporary gene flow among the metapopulations before the unusually hot summer of 2003,

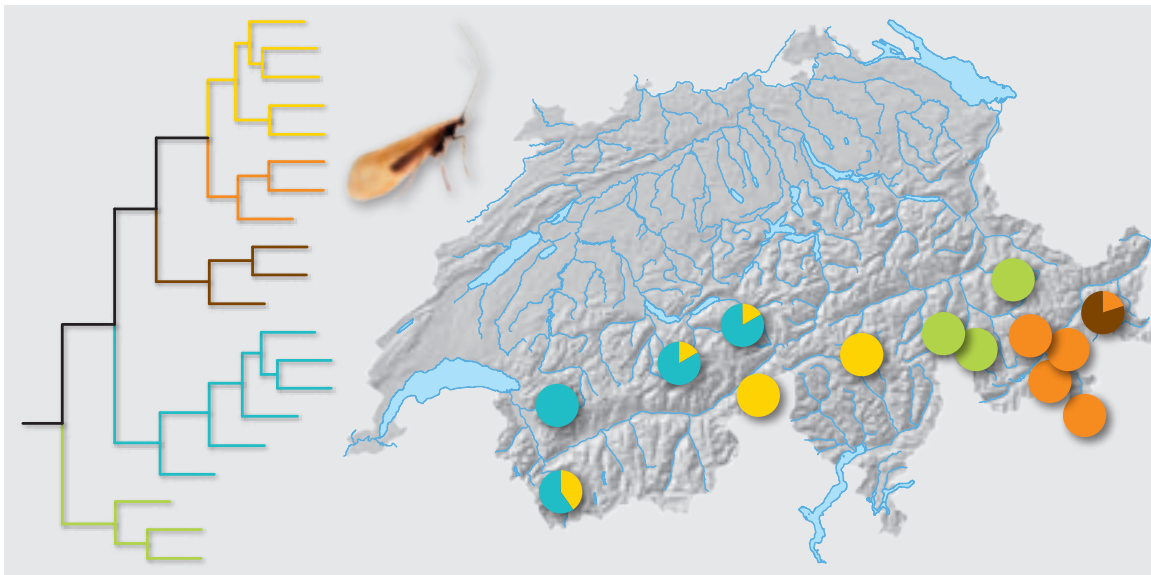


Fig. 2: Genetic divergence in the alpine caddisfly (*Allogamus uncatatus*) on the basis of a conserved gene region. The geographical distribution of the five groups indicates that the valleys have been colonized from different glacial refugia. The tree diagram represents the genetic relatedness of the populations, and the pie charts show the proportions of the different genetic variants found.

although some of the valleys examined were as far apart as 165 kilometres. But this pattern changed dramatically after the major drought of 2003: stocks of many metapopulations were decimated and only a small proportion of individuals survived. Such a drastic decrease in population size is called a population bottleneck: with the loss of so many individuals, most of the population-level genetic diversity was lost after the summer of 2003. Enhanced by genetic drift, the metapopulations now showed less genetic diversity and pronounced differences among each other [3]. But when the team compared populations within valleys, they found that local populations inhabiting either permanent or temporary streams were quite similar, suggesting that temporary habitat patches where populations frequently go extinct during an annual summer drought are recolonized locally [3]. Local population extinctions are a part of normal dynamics in natural ecosystems, but human impacts have made such extinction events more frequent and more dramatic.

The common alpine caddisfly (*Allogamus uncatatus*) is found in permanent or temporary streams in Alpine valleys, where local extinction of the more or less isolated populations is a common event.



Network of suitable habitats required. The viability of a metapopulation depends crucially on connected local populations. These ensure recolonization of temporary habitats after extinctions or catastrophic events. As such events are likely to become more common as a result of climate change, we can also expect population bottlenecks to continuously erode genetic diversity. Important genetic potential, enabling both local populations and metapopulations to adapt to environmental change, could thus be lost.

Inevitably, there is a time lag between the degradation of local populations and the actual collapse of the whole metapopulation. Effective conservation measures therefore need to be taken at the point when suitable habitat patches for populations become more scarce and landscapes become more fragmented. We cannot rely on just a few habitat patches. Restoration should aim to provide an adequate network of suitable habitats because stable and resilient metapopulations depend on the number of local populations, their connectedness and sufficient population sizes. Management and restoration efforts should therefore focus on healthy metapopulations of keystone species. This promises to be the least costly way of guaranteeing sustainable ecosystem function and services.

Connecting populations – a double-edged sword in management. Connectedness is usually a function of distance and isolation among populations. Geographically close or well-connected populations exchange more migrants and have more gene flow than populations which are separated by waterfalls, physical structures or long distances. Isolated or remote populations can therefore exhibit genetic divergence and potentially possess valuable novelties. When planning restoration projects, for example, one should try to avoid connecting such populations. Improving connectedness may rescue declining populations through increased migration, but it may also open the doors to the spread of invasive species or even disease.

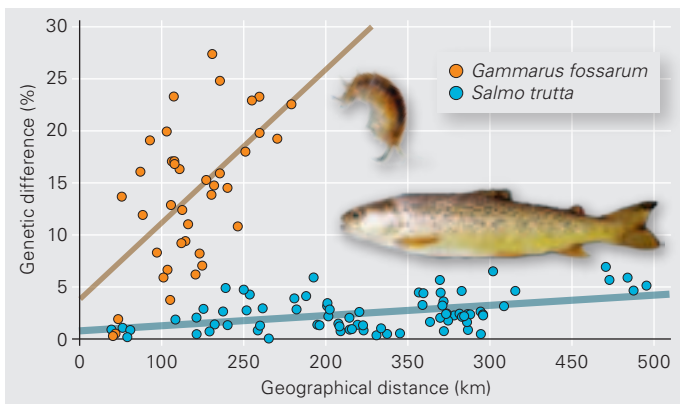


Fig. 3: The relationship between connectedness and genetic differences for local populations of brown trout (*Salmo trutta*) and the common freshwater amphipod (*Gammarus fossarum*). Data points indicate pairwise genetic differences between populations, plotted against the geographical distance between the same populations. Amphipod populations show greater genetic differences because of the low level of gene flow between populations.

The relationship between connectedness and genetic divergence can be illustrated by comparing the brown trout and the common freshwater amphipod *Gammarus fossarum* in the Rhine drainage basin: local populations of the highly mobile trout show a high degree of connectedness. For this reason, genetic differences among the populations are not very pronounced. Nevertheless, trout populations show a clear correlation between geographical distance and genetic distance. This indicates that gene flow is to some extent restricted and still generates locally divergent populations [1]. In the less mobile *Gammarus fossarum*, the relationship between geographical and genetic distance is much stronger. Despite small geographical distances the populations are genetically highly distinct [4], which indicates very limited gene flow and higher potential for local genetic adaptation (Fig. 3).

These are important findings for restoration measures. For example, we are interested in maintaining viable trout populations and manage them by stocking. But, depending on the origin of the stocked individuals, stocking may increase gene flow or homogenize local variants. In the case of *Gammarus*, we would like to maintain the local races, and deliberate relocation of *Gammarus* populations is to be avoided. In fact, active habitat restoration projects should seek to improve the viability of the regional metapopulations. Brown trout, which are predators of *Gammarus*, are also likely to benefit from such restoration measures, and stocking may then become unnecessary.

More precise planning. Ideally, regional restoration projects should be planned in such a way as to maximize the potential for preservation of local genetic diversity. This is best achieved by mapping the genetic structure of local populations, which reveals where metapopulations need to be supported, and where habitat patches need to be restored or created. With this kind of data, it is possible to avoid genetic novelties of more distant populations being diluted by unwanted gene flow. Restoration is thus a balancing act between improving local population viability

Glossary

<i>Ecological processes</i>	Interaction of organisms with each other and with their environment.
<i>Evolutionary processes</i>	In the sense of microevolution: generation-to-generation changes in allele frequencies within a population due to gene flow, genetic drift, mutation and natural selection.
<i>Gene flow</i>	The spread of genes from one population to another.
<i>Genetic drift</i>	Random changes in allele frequencies, especially in small populations, not due to natural selection.
<i>Glacial refugia</i>	Locations of isolated, relict populations of formerly widespread species, forced to retreat during the last ice age.
<i>Keystone species</i>	A species which has a disproportionate effect on its environment (relative to its biomass) and plays a key role in maintaining and defining the ecosystem.
<i>Local adaptation</i>	Evolution through natural selection of traits that have high fitness in specific environmental conditions (biotic or abiotic).
<i>Population bottleneck</i>	Dramatic decrease in population size, leading to a loss of genetic diversity.

by creating new habitat and, at the same time, maintaining the natural isolation between genetically distinct populations.

In freshwaters, restoration ecology has traditionally focused on restoring habitat heterogeneity and improving natural hydrology and habitat connectivity. The new emphasis on the value of local populations does not contradict the classical restoration principles, but demands more precision in planning of where and how restoration is to be applied. Restoration goals should be biologically justified, targeting keystone species that have an important functional role in the ecosystems and carry genetic novelties. This also requires many new skills on the part of practitioners. ○ ○ ○

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The future of water in a rapidly changing world

Society depends both on the direct use of water – for water supply, irrigated agriculture, waste assimilation, hydropower and navigation – and also on ecosystem services provided by the water environment. Safeguarding the provision of these ecosystem services will require that direct human needs for water are met in ways that minimize adverse impacts on the water environment.

Switzerland has a long history of successful management of its water infrastructure and water resources. With the headwaters of several major European rivers in the Swiss Alps, the management of its surface waters (including their water quality) can have significant international consequences for Switzerland. In addition, a heavy reliance on hydropower and need for flood protection have led to extensive alteration of the Swiss water environment.

Future decisions regarding water management in Switzerland will need to be made in a new context that incorporates not only past investments in infrastructure but also changing conditions and societal values. Both historical and global perspectives offer

Age-old water infrastructure: in Canton Valais, some of the traditional irrigation channels (known as Suonen or bisses) dating back over 1000 years are still in use today.



Keystone

a framework for examining the challenges that Switzerland faces in managing its water resources and infrastructure in the future.

A core responsibility of civil society. The management of water resources and water infrastructure has been a core responsibility of civil society throughout history. It is a testament to the central importance of water in sustaining societies that so many artefacts of water infrastructure – dating back thousands of years – can be found on nearly every continent. Throughout Europe, remnants of Roman aqueducts, baths and latrines are widespread. In Switzerland, a system of local irrigation channels (called Suonen in German and bisses in French) remains in use today in Canton Valais; the earliest use of this technology dates back to 900 CE.

Societies derive many benefits from the direct use of water and the water environment. The importance of water for health and hygiene was recognized by ancient civilizations and has recently been accorded the status of a human right by the United Nations. Water and the water environment also support terrestrial ecosystems, including rain-fed and irrigated agriculture, and aquatic ecosystems, including fisheries. Water provides means for transportation and power generation and also aesthetic and recreational benefits to society.

Many of these direct benefits can only be tapped through the construction of infrastructure, from the simplest channels to massive dams. This infrastructure represents a substantial investment on the part of society (see article by page 22). Much of this infrastructure also dramatically alters, either by design or necessity, the pre-existing conditions of the water environment – for example, with regard to river flow and morphology. In Switzerland, the early development of major water infrastructure (in the early 19th century) was related to flood control and the reclamation of land for agriculture and settlement.

Alteration of the water environment. Water diversion and the alteration of flow conditions are among the most profoundly deleterious consequences of water infrastructure and of the allocation of water resources to meet direct human needs. The ecological devastation of the Aral Sea (located on the border of



Eawag Director Janet Hering has specialized in techniques for making contaminated water drinkable and in the biogeochemical behaviour of trace metals. She holds professorships at the ETH Zurich and the EPF Lausanne.

Uzbekistan and Kazakhstan) was the result of decades of water diversion for irrigated agriculture. In some countries, major rivers, such as the Colorado River in the US, no longer reach their natural estuaries, leading to the collapse of those ecosystems.

In Switzerland, the principal alterations of waterways include river channelization and construction of dams. There are approximately 88,000 artificial barriers over 0.5 metres high along Swiss rivers, and in Canton Zurich there are approximately 11 artificial barriers per kilometre. Of the entire Swiss river network of 65,300 kilometres, approximately 15,800 kilometres (or 24 per cent) have an unsatisfactory morphological status [1]. Large rivers at low elevations are disproportionately represented in this group, which includes 50 per cent of the rivers below 600 metres and 48 per cent of the rivers wider than 5 metres. Many Alpine rivers are affected by either insufficient residual flows due to 1400 water intakes for hydropower or hydropeaking below the power plants. In addition, rivers are cut off from their natural floodplains. In 2003, guiding principles for Swiss river management were developed that identified the need for adequate space, water flows and water quality for waterways, but this has been of little consequence where water infrastructure is already in place.

The alteration of Swiss waterways and even the more consequential alterations of waterways in other countries have impacts only on local or regional scales. Historically, these have been the scales on which human activities have had their impacts on the water environment, but today a global perspective is needed.

Global change and future challenges. With the release of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) in 2007, the potential consequences of global climate change for the hydrological system at regional and national scales have received increasing attention [2]. Changes in average annual precipitation are not anticipated in Switzerland, but

anticipated changes in seasonal patterns could result in drier summers and wetter winters (Figure 1). The increased precipitation anticipated in winter combined with a shift in precipitation from snow to rain could also result in increased danger of flooding. The retreat of Swiss alpine glaciers is well established, with about 50 per cent loss of areal extent between 1850 and 2000.

Worldwide, it is estimated that almost one-fifth of the world's population is exposed to physical water scarcity, defined as the consumptive use of more than 75 per cent of renewable water resources to meet human needs [3]. An even greater number of people face economic water shortages resulting in both malnutrition and disease associated with poor sanitation and a lack of safe drinking water. Although the Millennium Development Goals aim to reduce by half the number of people without access to safe drinking water and basic sanitation by 2015, it is considered unlikely that the sanitation target will be met (see article by page 26).

The international issues of water and development call for a response on humanitarian grounds. There will, however, also be opportunities for the development of new concepts and technologies related to water supply and waste treatment in developing and emerging countries. In arid and semi-arid climates, water scarcity limits the feasibility of centralized sewage treatment systems that rely on water for waste conveyance. Decentralized treatment offers a less water-intensive alternative, with the additional advantage of enabling nutrient recovery from source-separated waste streams (see article by page 30).

With the increasing pressures of global climate change, population growth and changes in consumption patterns, the historical past no longer provides a reliable guide for the future. New strategies will be needed to manage water resources and to plan and construct water infrastructure so that both future changes in environmental and societal conditions and the uncertainties in the responses of environmental systems can be accommodated.

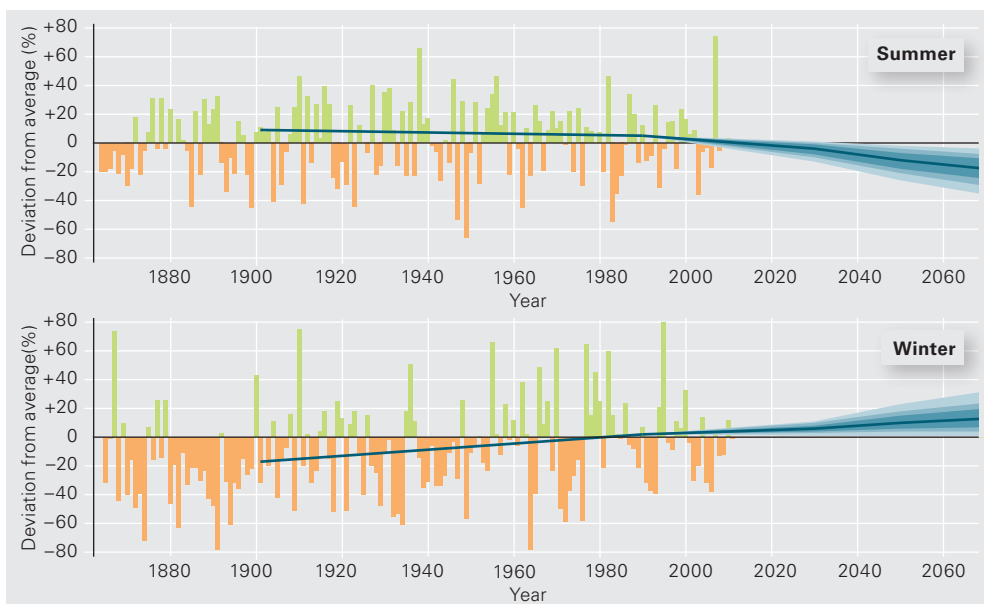


Fig. 1: Predicted precipitation for Switzerland under the influence of climate change. The graph shows average rainfall for the period 1864–2010 (measured) and scenarios for the period up to 2070, compared with the average for 1961–1990. Winter rainfall is expected to be higher and summer rainfall lower than in the past (adapted from Meteo-Swiss/ETH Zurich).

Developments in water management. Future water-related issues in Switzerland will be more complex than in the past, and hence their management will require greater integration and adaptive capacity. Future management decisions are influenced by past investments in infrastructure (see article by page 22). Water infrastructure has a long lifetime (typically about 80 years) and, during this time, various external conditions may evolve. Figure 2 illustrates this point by comparing the build-up of reservoir storage capacity over the period 1850–2010 with changes in population and the timing of key federal legislation.

The ecological effects of hydropower production are a case in point. The construction of large dams with substantial storage capacity necessarily entails a loss of riparian habitat in the flooded region (as shown in Figure 3). Such losses are thus part of the trade-off in the societal decision to construct dams. In the past, such losses were considered acceptable; the Rossens Dam (which impounds the area shown in Figure 3) was completed in 1947, forming the Lake Gruyère with a surface area of 960 hectares. In contrast, a dam project that would have flooded the Greina high plateau was abandoned in the late 1980s – in part because of strong citizen efforts to protect the riparian habitat (www.greina-stiftung.ch/). In 1991, the Federal Water Protection Act introduced minimum requirements for residual flow that should be implemented by the cantons by 2012, but progress has been slow. The lack of clarity regarding compensation for reduced energy production has been an important impediment to implementing ecological flow regimes. The 2010 revision to this Act has allocated federal funds both for river restoration and for mitigating the environmental impacts of hydropeaking and river fragmentation.

The need for integration and adaptive management. Many future issues in water resources and water infrastructure manage-

ment will involve an explicit balancing of societal objectives. Other problems, such as the occurrence of micropollutants in surface and groundwater, may be addressed through a variety of different measures (see article by page 14). At the same time, current scientific understanding often does not allow a definitive prediction of the outcomes of management alternatives. Advances in the underlying science are needed to understand, for example, the propagation of effects across scales from the subcellular to the ecosystem level and the relationship of biodiversity to the resilience of ecosystem function (see article by page 34). In addition, the uncertainty in scientific predictions must be explicitly addressed if such predictions are to support societal decision-making.

At the stage of problem definition and framing, a broad, cross-sectoral perspective can expand the portfolio of measures or approaches that could be employed to meet societal objectives. Correspondingly, an integrated approach on the watershed scale has been advocated through the stakeholder platform Water Agenda 21 (www.wa21.ch/index.php?page=311), which is consistent with international agreements on integrated water resources management [5]. As the process of problem definition proceeds, however, a pragmatic evaluation of the appropriate level of integration is needed. Integrated planning across sectors is of little benefit if resources cannot be redirected among them. In addition, realized synergies should be larger than the additional cost to handle increased complexity.

In developing concrete plans for new infrastructure investments or management strategies, explicit formulation and structuring of objectives are useful both to increase transparency and to distinguish the objectives clearly from the measures that might be taken to achieve them. This distinction is particularly important in light of the uncertain outcome of alternative measures and the possibility that evolution of societal values might lead to a change

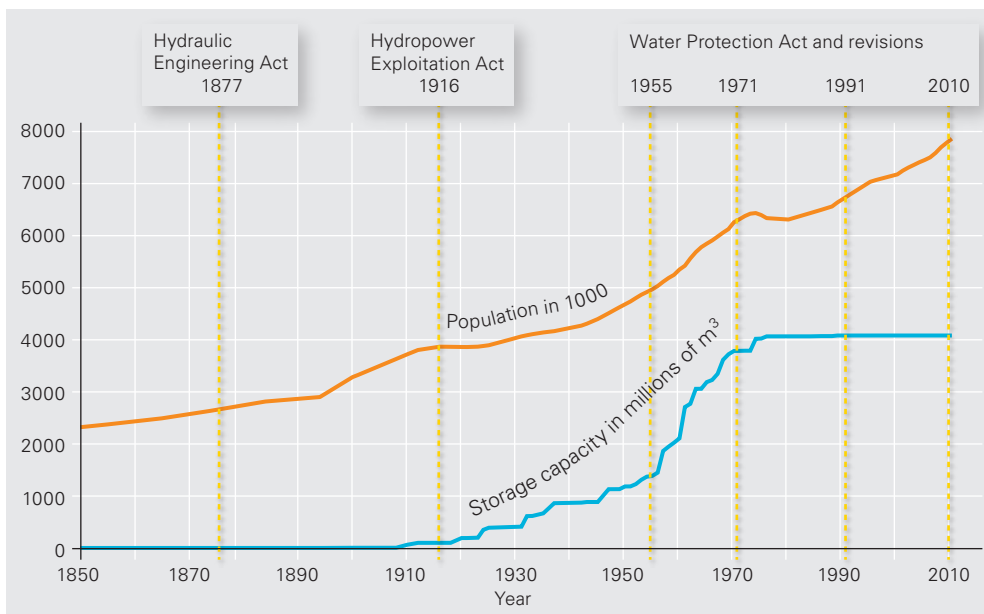


Fig. 2: Timing of key federal legislation compared with growth of the population and reservoir storage in Switzerland. The first two versions of the Water Protection Act (1955 and 1971) were concerned with pollution control (qualitative water protection), and the 1991 revision also specified minimum requirements for residual flows (quantitative water protection). The 2010 revision aims to promote river restoration and mitigation of hydropeaking (sources: Wikipedia, www.swissdams.ch).

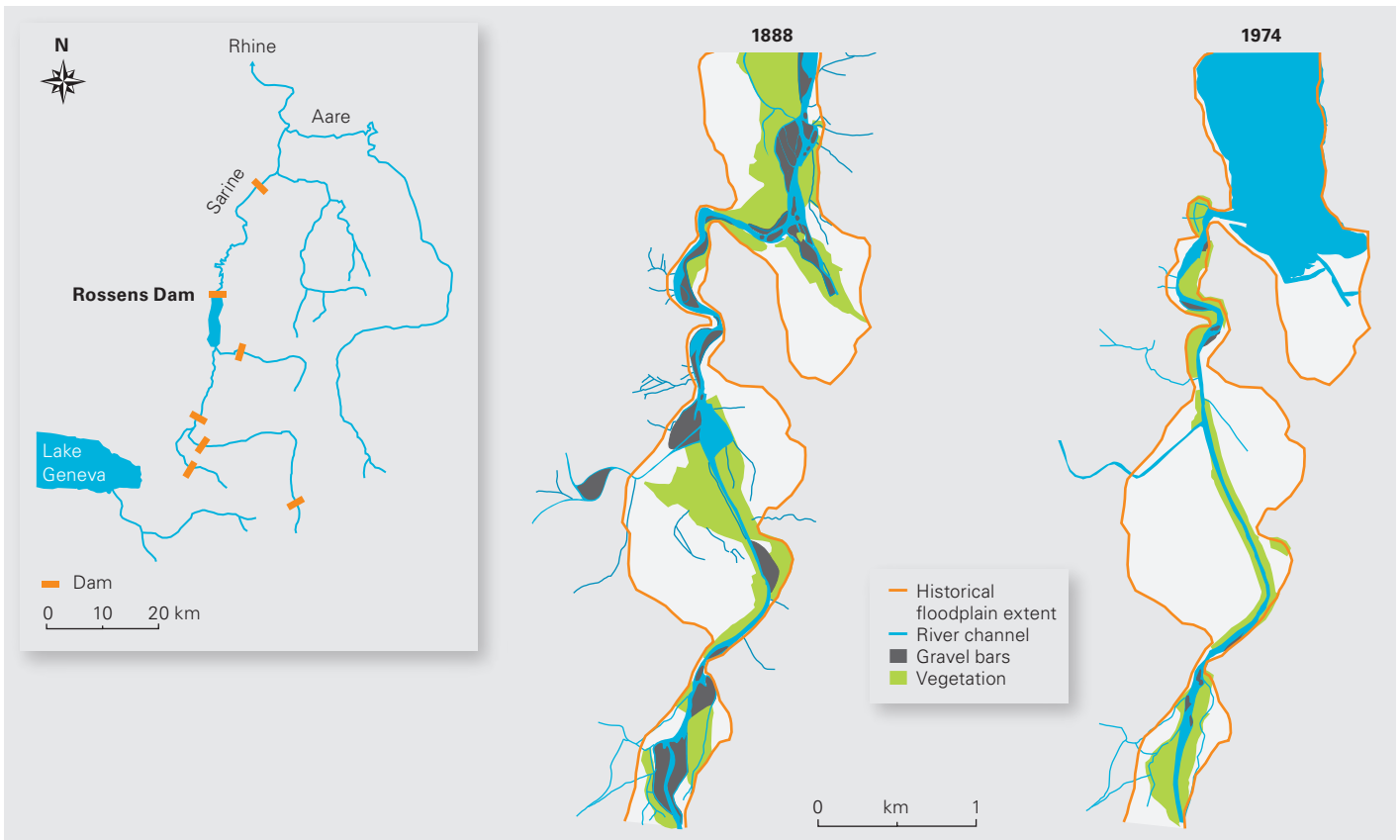


Fig. 3: Evolution of floodplain morphology after the construction of the Rossens Dam (Canton Fribourg) [4].

in the desirability of achieving specific objectives at a later time. The selection of measures with greater adaptive capacity also provides a hedge against both uncertainty in outcomes and changes in societal values. Frameworks based on decision theory have been applied in the context of river restoration [6] and are being developed further to incorporate a broader scope of integration.

Outlook. It has been apparent for many years that the direct human use of water can have extremely deleterious impacts on the water environment. But the appreciation of the ecosystem services provided by the water environment – and the need to safeguard those services – is comparatively recent. An explicit balancing of objectives, supported by scientific understanding that allows reliable prediction, is needed for societal decision-making on water-related issues. In Switzerland, issues that must be addressed today and in the coming years include conservation of biodiversity, control of invasive species, and mitigation of the ecological effects of micropollutants and hydropower. Switzerland can also use its experience in the management of water infrastructure and water resources to benefit people and protect the environment in developing and emerging countries. At the same time, Switzerland can benefit from the opportunity to bring novel concepts and technologies into practice through these efforts. ○ ○ ○

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Retirement of Willi Gujer

Willi Gujer, formerly Professor of Urban Water Management at the ETH Zurich and a member of the Eawag Directorate, retired in January 2011. From 1976 to 1994, he was head of the Engineering Sciences department at Eawag. From 1992, he also served as Professor of Urban Water Management and assumed various management roles at the ETH Zurich. Gujer was a key figure in the development of wastewater treatment technologies in Europe.



He also attached particular importance to the training of specialists in urban water management. His commitment to higher education was widely recognized – he received the “Golden Owl” from the ETH student association in 2006 and the “Credit Suisse Award for Best Teaching” in 2008. On 21 October 2011, a symposium in his honour will be held at the Empa Academy in Dübendorf. www.eawag.ch/medien/veranstaltungen/20111021

Methane-from-wood technology

The production of methane from wood – synthetic natural gas (Bio-SNG) – offers a strategic addition to established energy technologies. As shown by an Eawag study, the process could be implemented in Switzerland under certain conditions. The study recommends, for example, that a Bio-SNG plant should be located near a large wood-processing facility so as to reduce costs for wood transport and fuel. It also points out that there is competition between different wood-based energy technologies. The new Bio-SNG technology could lose out, as wood-based energy plants have a lifespan of 15–20 years. A Bio-SNG plant will probably only be established when another plant needs to be replaced. Contact: steffen.wirth@eawag.ch

Mini-submersibles diving in Lake Geneva

Since the end of May, two Russian Mir submersibles have been operating near Le Bouveret on Lake Geneva. Over the next few months, they will be used by an international research team (led by the EPF Lausanne) to explore the depths of the lake. Eawag is responsible for four of the projects, focusing on the Rhône delta. Here, sediment deposits have accumulated over the millennia, forming underwater canyons. Eawag researchers will be using the mini-submersibles to investigate the behaviour of these deposits, the stability of the lake bed topography and sediment-water exchange processes. For example, the collection of horizontal sediment cores from the sides of the underwater canyons should provide information on the stability of the steep delta slopes. Large-scale sediment slides in lakes can cause devastating tsunami-type waves, but they can also explain structures on and in the lake bed beyond the delta and are responsible for extensive dispersal of disturbed matter.



Ecotoxicology research without animal experiments

Eawag has recently become a member of EUROECOTOX, a European network committed to the replacement and reduction of animal experiments in ecotoxicology. EUROECOTOX is funded by the European Commission's FP7 Environment Research programme. www.euroecotox.eu



Second term for Janet Hering

At the request of the ETH Board, Janet Hering has been reappointed by the Federal Council as Director of Eawag for a second term, running until 2014. Hering has been Director of the Swiss Federal Institute of Aquatic Science and Technology since the beginning of 2007 and has held a dual professorship at the ETH Zurich and the EPF Lausanne since May 2010. Together with the Eawag Directorate, Hering is currently completing work on the



Strategic Plan for 2012–2016. The key question to be addressed is how human needs for water can be satisfied while at the same time preserving the aquatic environment and essential ecosystem services. Photo: ETH Board President Fritz Schiesser, Janet Hering and ETH Zurich President Ralph Eichler at the reception held to mark her reappointment.

Climate prize for air-stripping

The Eawag project “Nitrogen recycling with air-stripping at the Kloten/Opfikon wastewater treatment plant” has received an award from the Zurich Insurance Company. The project – carried out by the Kloten/Opfikon WWTP and a team led by Marc Böhler, with financial support from the Canton Zurich Office for Waste, Water, Energy and Air (AWEL) – received a special prize for innovation at the Zurich Climate Award ceremony. The Process Engineering department project – involving Marc Böhler (left), Hansruedi Siegrist (not pictured), Sandra Büttner and other partners – is pioneering in many respects. With the air-stripping method, nitrogen can be recovered from sludge liquid as ammonium sulphate fertilizer, thus virtually closing the nitrogen cycle. In addition, further pretreatment of the sludge liquid reduces energy consumption for the process. The project at the Kloten/Opfikon WWTP was the first-ever full-scale implementation of the method in Switzerland. Also to be investigated is co-treatment of



source-separated urine collected at Eawag headquarters, with the goal of demonstrating a cost-effective and energy-efficient way of processing urine into a commercial product. www.eawag.ch/forschung/eng/schwerpunkte/abwasser/luftstrippung

New head of Ecotox Centre

In September 2010, Inge Werner (53) took up her position as head of the Eawag EPFL Ecotox Centre. From 1996, Werner – who has dual US/German citizenship – conducted environmental research at the UC Davis School of Veterinary Medicine and served as an Associate Adjunct Professor. For the last five years, she was Director of the Aquatic Toxicology Laboratory there. The ATL is a



State-certified lab which investigates surface water quality and aquatic ecosystem health throughout California. Werner – who has a PhD in zoology – carried out numerous applied projects in aquatic ecotoxicology, in cooperation with State and local authorities. www.oekotoxzentrum.ch

In Brief

Hot off the presses

April 2011 saw the publication of a trilingual (English, French and German) booklet to mark Eawag's 75th anniversary – "**Eawag: past, present and future**".



In six sections, it provides an informative and entertaining account of aquatic research at Eawag. As Director Janet Hering notes in the Editorial, Eawag's strengths have always included learning from the past, acting in the present and planning for the future.

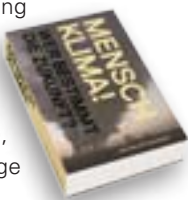
The booklet can be ordered free of charge from info@eawag.ch. It is also available online at: www.eawag.ch/75jahre

The fifth edition of "**Aquatische Chemie**" by Laura Sigg and Werner Stumm has now appeared (vdf-Hochschulverlag, ISBN: 9783825284633).



This textbook covers the principles of aquatic chemistry and the chemistry of aqueous solutions, and their application to natural waters and other aquatic systems. It thus lays the foundations for an understanding of chemical processes in natural waters and in engineered wastewater and drinking water treatment systems.

Also hot off the presses is "**For Climate's Sake! Who's in Charge of the Future?**" co-edited by René Schwarzenbach (Lars Müller Publishers, ISBN: 978-3-03778-245-3). This illustrated reader uses reportage, case studies and striking image sequences to shed light on climate change. As well as discussing the history of the earth and of climate, and climate drivers (solar energy, greenhouse gases and global warming), it addresses the consequences of climate change and political strategies designed to combat it.



Assessment of micropollutants

The quality of Swiss surface waters is adversely affected by micropollutants from municipal wastewater. On behalf of the Federal Office for the Environment, Eawag and the Ecotox Centre have now developed a guide designed to help political decision-makers plan further studies or measures to control micropollutants. The "Concept for the assessment of organic micropollutants in urban wastewater" (in German) offers detailed guidance on identifying contaminated waterbodies, assessing water quality, determining the sources of pollutants and evaluating possible measures. www.eawag.ch/forschung/uchem



Agenda

Courses

4–15 July 2011, Eawag Kastanienbaum

PhD Summer School: Sediments as archives of environmental change

6–7 September 2011, Eawag Dübendorf

Evolutionsökologie im Gewässerschutz (in German)

29–30 September 2011, Eawag Dübendorf

Mikroverunreinigungen in Oberflächengewässern mit Schwerpunkt hormonaktive Substanzen (in German)

6–7 October 2011, Eawag Dübendorf

Erfolgreiche Revitalisierung von Fließgewässern (in German)

2–4 November 2011, Emmetten

VSA course: Mikroverunreinigungen und Aspekte zu Energie und Stickstoff (in German)

16–17 November 2011, Eawag Dübendorf

Bewertung von Oberflächengewässern: Konzepte und Implementation (in German)

7–8 December 2011, Eawag Dübendorf

Sanitation planning tools in developing countries

Guided tours

22 September 2011, Eawag Kastanienbaum

Public tour of the Kastanienbaum site

Events

11–15 September 2011, ETH Zurich

Emerging issues in environmental chemistry: from basic research to implementation

21 October 2011, Eawag Dübendorf

Symposium in honour of Professor Willi Gujer

3 November 2011, Landhaus Solothurn

4th ChloroNet conference

Further information: www.eawag.ch/veranstaltungen

Gates Foundation support for urine project

The Bill & Melinda Gates Foundation is providing a CHF 3 million grant to support a project jointly run by Eawag and eThekwini Water and Sanitation in Durban, South Africa. The focus is on separate collection of urine, promoting innovative ways of improving sanitation and enabling recycling of nutrients (nitrogen, phosphorus and potassium). The project manager at Eawag is Kai Udert of the Process Engineering department. www.eawag.ch/vuna

Eawag publications

A database of all publications by Eawag researchers (including article summaries) is available online at:

www.lib4ri.ch/institutional-bibliography/eawag.html

Open access publications can be downloaded free of charge.

If you have any queries, please contact: info@lib4ri.ch